ESTIMATION OF GREENHOUSE GASES FROM COMBUSTION FACILITIES IN JUBAIL INDUSTRIAL CITY (JIC) AND YANBU INDUSTRIAL CITY (YIC)

BY

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This Thesis Is Dedicated

To:

My beloved parents for their prayers and my family for their tender care and efforts.

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THESIS ABSTRACT

NAME: **HAMAD H. AL-ABBAS**

TILTLE OF THE STUDY: **Estimation of Greenhouse Gases from Combustion Facilities in Jubail Industrial City (JIC) and Yanbu Industrial City (YIC)**

MAJOR FIELD: **ENVIRONMENTAL SCIENCES**

DATE OF DEGREE: MAY 2012

The Intergovernmental Panel on Climate Change (IPCC) concludes that "most of the observed increase in globally averaged temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations" via the greenhouse effect. Carbon dioxide (CO_2) is one of the most foremost greenhouse gases in the atmosphere. This study estimate the greenhouse gases concentrations from the combustion facilities (i.e boilers, heaters, furnaces, flares, incinerators etc.) in Jubail Industrial City (JIC) and Yanbu Industrial City (YIC) and was conducted in line with the IPCC methodologies for the estimation of greenhouse gases using fuel consumption data from combustion facilities in petrochemical plants. The study process was divided into five (5) main parts: data collection, data processing, statistically and greenhouse gases emission trends analysis. We developed ten (10) fuel consumption emission scenarios to establish the "best fit" fuel as a substitute for Natural gas usage. The result showed that no individual or blended fuel types resulted in an overall decrease of greenhouse and non-greenhouse gases emission. Generally, blended fuel scenarios gave reduction in levels of Greenhouse gases emissions as would have been expected but Scenarios **6**, **8** and **10** gave promising replacement fuel in the event Natural gas shortfall while the other six scenarios tailed along . The scenarios were also ranked according to their performance in the levels of non-greenhouse gases, which include NO_x, CO, NMVOC and SO_2. Scenarios **2,4,8** and **10** were on the borderline while scenarios **3, 5, 7 and 9** are at the bottom of the ranking table. Overall, scenarios **6, 8** and **10** represent the best substitute blends in consideration of their greenhouse and non-greenhouse emissions. This study will provide important baseline data for the emission trends in greenhouse gases in Jubail and Yanbu industrial cities (CO_2 , CH_4, N_2O …) and advise on best fuel alternative in case of shortage or total stoppage of the currently used Natural gas

ملخص الدراسة

الاسم / حمد بن حسين بن علي ال عباس

عنوان الرسالة / الحساب التقديري لكمية الغازات الدفيئة المنبعثة من مرافق الاحتراق في كل من مدينة الجبيل وينبع الصناعيتين

التخصص علوم البيئة

التاريخ سبتمبر - 2011

خلص الفريق الحكومي العالمي والمعني بالتغيير المناخي إلى أن" الزيادة الملحوظة في متوسط درجات الحرارة عالمياً ومنذ منتصف القرن العشرين يعود وبشكل واضح الى الزيادة في تركيزات الغازات الدفيئة والناتجة من النشاط البشري" مما أدى الى ظاهرة الأحتباس الحراري ويُعد ثاني أكسيد الكربون (CO_2) أكثر الغازات الدفيئة انتشاراً في الغلاف الجوي .

في هذه الدراسة نقوم بحساب تقديري لتراكيز الغازات الدفيئة المنبعثة من مرافق الاحتراق كالغلايات والمداخن والمشاعل والمحارق وغيرها في كل من مدينتي الجبيل وينبع الصناعيتين.

تتبع هذة الدراسة المنهجية والمعايير المعتمدة من قبل المنظمة الدولية والمعنية بالتغير المناخي التابعة للأمم المتحدة (IPCC) في عملية تحديد إنبعاثات الغازات الدفيئة وذلك بإستخدام كمية الوقود المستهلك في مرافق الأحتراق للمصانع البتروكيماوية.

تتضمن هذه الدراسة خمسة أجزاء رئيسة وهي: جمع البيانات من الجهات ذات العلاقة، ومعالجة البيانات وتحليلها إحصائيا ، إستكشاف إتجاهات إنبعاثات الغازات الدفيئة ودراسة الأتجاهات الفعلية والمتوقعة وذلك للوصول لأفضل البدائل للغاز الطبيعي. سوف توفر هذه الدراسة قاعدة أساسية هامة لإتجاهات إنبعاث الغازات الدفيئة المسببة للاحتباس الحراري (CO_2, CH_4, N_20) وتقدم المشورة العلمية بشأن أفضل البدائل في حالة النقص أو التوقف الكلي للغاز الطبيعي المستخدم حاليا في كل من المدينتين الصناعيتين.

ABBREVATIONS

- CH_4 = methane
- CO_2= Carbon dioxide
- N_2O = Nitrous oxide
- $2H_2O$ =water vapor
- NMVOC = Non methane volatile organic compound
- NOx = nitric oxide and nitrogen dioxide
- SO_2 = Sulfur dioxide,
- O_3 = ozone
- IPCC =Intergovernmental Panel on Climate Change
- GWP = Greenhouse gas warming potential
- UNFCCC= United Nations Framework Convention on Climate Change

Scenarios	**Fuel Mix**
1	100% Natural Gas (Normal Case)
2	100% Crude Oil
3	100% Diesel Oil
4	100% Fuel Oil (worst case)
5	50% Natural Gas + 50% Crude Oil
6	70% Natural Gas + 30% Crude Oil
7	50% Natural Gas + 50% Diesel
8	70% Natural Gas + 30% Diesel
9	50% Natural Gas + 50% Fuel Oil
10	70% Natural Gas + 30% Fuel Oil

CHAPTER ONE

INTRODUCTION

SIGNIFICANCE OF GREENHOUSE GASES

Greenhouse gases absorb and emit radiation within the thermal infrared range in the atmosphere, this process is the fundamental cause of the greenhouse effect (IPCC, 2007). The primary greenhouse gases in the Earth's atmosphere are water vapor ($2H_2O$), carbon dioxide (CO_2), methane (CH_4), nitrous oxide (NO), and ozone (O_3). Today, the most significant global environment problem faced by the world community is associated to global environmental changes due to a host of factors such as greenhouse gases emissions at rapid rate, deforestation and ozone layer depletion (Yüksel, 2007; IPCC 2006a). The high-accuracy measurements of atmospheric carbon dioxide (CO_2) concentration, initiated by Keeling (1958), constitute the master time series documenting the changing composition of the atmosphere. These data have iconic status in climate change science as evidence of the effect of human activities on the chemical composition of the global atmosphere. Keeling's measurements on Mauna Loa in Hawaii provide a true measure of the global carbon cycle, an effectively continuous record of the burning of fossil fuel (Keeling, 1958). They also maintain an accuracy and precision that allow scientists to separate fossil fuel emissions from those due to the natural annual cycle of the biosphere, demonstrating a long-term change in the seasonal exchange of carbon dioxide CO_2 between the atmosphere, biosphere and ocean. Later observations of parallel trends in the atmospheric abundances of the $^{13}CO_2$ isotope

(Francey and Farquhar, 1982) and molecular oxygen (O_2) (Keeling and Shertz, 1992; Battle *et al.,* 1996) uniquely identified this rise in carbon dioxide CO_2 with fossil fuel burning.

FACTORS DETERMINE EARTH'S CLIMATE

The climate system is a complex, interactive system consisting of the atmosphere, land surface, snow and ice, oceans and other bodies of water, and living things. The atmospheric component of the climate system most obviously characterizes climate; climate is often defined as 'average weather'. Climate is usually described in terms of the mean and variability of temperature, precipitation and wind over a period of time, ranging from months to millions of years (the classical period is 30 years). The climate system evolves in time under the influence of its own internal dynamics and due to changes in external factors that affect climate (called 'forcings'). External forcings include natural phenomena such as volcanic eruptions and solar variations, as well as human-induced changes in atmospheric composition. Solar radiation powers the climate system. There are three fundamental ways to change the radiation balance of the Earth: 1) by changing the incoming solar radiation (e.g., by changes in Earth's orbit or in the Sun itself); 2) by changing the fraction of solar radiation that is reflected (called 'albedo'; e.g., by changes in cloud cover, atmospheric particles or vegetation); and 3) by altering the longwave radiation from Earth back towards space (e.g., by changing greenhouse gas concentrations). Climate, in turn, responds directly to such changes, as well as indirectly, through a variety of feedback mechanisms.

The amount of energy reaching the top of Earth's atmosphere each second on a surface area of one square meter facing the Sun during daytime is about 1,370 Watts, and the amount of energy per square meter per second averaged over the entire planet is one-quarter of this (Figure 1) (Kiehl and Trenberth 1997). About 30% of the sunlight that reaches the top of the atmosphere is reflected back to space. Roughly two-thirds of this reflectivity is due to clouds and small particles in the atmosphere known as 'aerosols'. Light-colored areas of Earth's surface – mainly snow, ice and deserts – reflect the remaining one-third of the sunlight. The most dramatic change in aerosol-produced reflectivity comes when major volcanic eruptions eject material very high into the atmosphere. Rain typically clears aerosols out of the

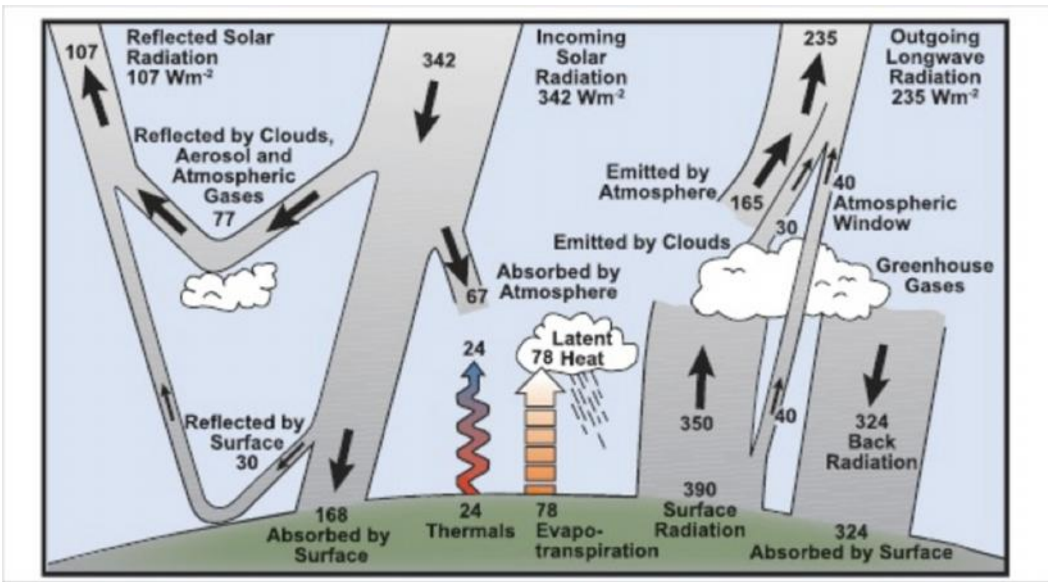

Figure 1 Estimate of the Earth's annual and global mean energy balance. Source: Kiehl and Trenberth (1997)

atmosphere in a week or two, but when material from a violent volcanic eruption is projected far above the highest cloud, these aerosols typically influence the climate for about a year or two before falling into the troposphere and being carried to the surface by precipitation. Major volcanic eruptions can thus cause a drop in mean global surface temperature of about half a degree Celsius that can last for months or even years (Kiehl and Trenberth 1997). Some man-made aerosols also significantly reflect sunlight.

The energy that is not reflected back to space is absorbed by the Earth's surface and atmosphere. This amount is approximately 240 Watts per square meter (W m^{-2}) (IPCC 2007). To balance the incoming energy, the Earth itself must radiate, on average, the same amount of energy back to space. The Earth does this by emitting outgoing long wave radiation. Everything on Earth emits long wave radiation continuously. That is the heat energy one feels radiating out from a fire; the warmer an object, the more heat energy it radiates. To emit 240 W m^{-2}, a surface would have to have a temperature of around –19°C. This is much colder than the conditions that actually exist at the Earth's surface (the global mean surface temperature is about 14°C). Instead, the necessary –19°C is found at an altitude about 5 km above the surface (IPCC 2007).

The reason the Earth's surface is this warm is the presence of greenhouse gases, which act as a partial blanket for the longwave radiation coming from the surface. This blanketing is known as the natural greenhouse effect. The most important greenhouse gases are water vapour and carbon dioxide. The two most abundant constituents of the atmosphere – nitrogen and oxygen – have no such effect. Clouds, on the other hand, do exert a blanketing effect similar to that of the greenhouse gases; however, this effect is offset by their reflectivity, such that on average, clouds tend to have a cooling effect on climate (although locally one can feel the warming effect: cloudy nights tend to remain warmer than clear nights because the clouds radiate longwave energy back down to the surface). Human activities intensify the blanketing effect through the release of greenhouse gases. For instance, the amount of carbon dioxide in the atmosphere has increased by about 35% in the industrial era, and this increase is known to be due to human activities, primarily the combustion of fossil fuels and removal of forests. (Kiehl and Trenberth 1997) Thus, humankind has dramatically altered the chemical composition of the global atmosphere with substantial implications for climate.

Because the Earth is a sphere, more solar energy arrives for a given surface area in the tropics than at higher latitudes, where sunlight strikes the atmosphere at a lower angle. Energy is transported from the equatorial areas to higher latitudes via atmospheric and oceanic circulations, including storm systems. Energy is also required to evaporate water from the sea or land surface, and this energy, called latent heat, is released when water vapour condenses in clouds (see Figure 1). Atmospheric circulation is primarily driven by the release of this latent heat. Atmospheric circulation in turn drives much of the ocean circulation through the action of winds on the surface waters of the ocean, and through changes in the ocean's surface temperature and salinity through precipitation and evaporation.

Due to the rotation of the Earth, the atmospheric circulation patterns tend to be more east-west than north-south (IPCC 2007). Embedded in the mid-latitude westerly winds are large-scale weather systems that act to transport heat toward the poles. These weather systems are the familiar migrating low- and high-pressure systems and their associated cold and warm fronts. Because of land-ocean temperature contrasts and obstacles such as mountain ranges and ice sheets, the circulation system's planetary-scale atmospheric waves tend to be geographically anchored by continents and mountains although their amplitude can change with time. Because of the wave patterns, a particularly cold winter over North America may be associated with a particularly warm winter elsewhere in the hemisphere (IPCC 2007). Changes in various aspects of the climate system, such as the size of ice sheets, the type and distribution of vegetation or the temperature of the atmosphere or ocean will influence the large-scale circulation features of the atmosphere and oceans.

There are many feedback mechanisms in the climate system that can either amplify ('positive feedback') or diminish ('negative feedback') the effects of a change in climate forcing. For example, as rising concentrations of greenhouse gases warm Earth's climate, snow and ice begin to melt. This melting reveals darker land and water surfaces that were beneath the snow and ice, and these darker surfaces absorb more of the Sun's heat, causing more warming, which causes more melting, and so on, in a self-reinforcing cycle. This feedback loop, known as the 'ice-albedo feedback', amplifies the initial warming caused by rising levels of greenhouse gases. Detecting, understanding and accurately quantifying climate feedbacks have been the focus of a great deal of research by scientists unravelling the complexities of Earth's climate.

IMPACTS OF GLOBAL CLIMATE CHANGE IN SAUDI ARABIA

Most of Saudi Arabia has sensitive ecosystem for any level of climate change especially on desertification processes. Assessment of these impacts indicated clearly that most regions have high vulnerability levels for climate change impacts on desertification processes. The climate change impacts as represented by temperature increase, would elevate the levels of reference evapo-transpiration by about 1-4.5% at 1°C increase, and by about 6-19.5% at 5 °C increase in most regions (Al-Harazin and Abderrahman 2003). The expected yield losses of different types of field crops (including cereals, vegetables and forage crops) and fruit trees (including date palms) will range between 5 and more than 25% (Al-Harazin and Abderrahman 2003). The value of these losses represent more than the actual profit for farmers from agricultural activities in different regions of the Kingdom. This represents a serious challenge to survival of the agricultural sector as a major economic sector in the national economy. Compensation of the crop losses importation from foreign countries represent additional burden on the economy. Furthermore, the agricultural activities represent a major support for about 25% of the national population who still live in rural areas. The deterioration of agriculture for rural communities represents a threat to the social structure and welfare of these communities. The natural plants in range lands and the cultivated crops will suffer from water shortages, as the very low annual rainfall in the majority of the regions cannot compensate for the elevated plant water requirements. Additionally, the topsoil layers in rangelands and in irrigated areas will suffer from salinization and increase of salinity levels by 2.8 times the original salinity levels (Alkolibi, 2002). Hence, the flora in all regions will be under increasing vulnerability for disease out breaks, retarded growth and collapse. Plant cover will be reduced and lands will be more exposed for erosion and desertification. This will lead to serious effects on social and economic development and sustainability of the national economy and progress of the country. In the process of desertification, factors such as degradation of soil organic and nutrient contents, deterioration of soil structure and salinity built up will lead to more evapo-transpiration and less water supplies to less productive lands to support the rural communities that depend on it. This will be more pronounced in the rangelands, which provide natural grazing for animals belonging to rural communities especially the nomads such as sheep and camels in all regions of the Kingdom. The reduction in surface moisture or vegetation cover would increase temperatures and reduce rainfall as less energy is used in evapo-transpiration and less water is recycled. Desertification is likely to become irreversible if the environment becomes drier and the soil is further degraded as a result of erosion and compaction. The most serious impacts on livestock production would be in the northern, southern and central parts of Saudi Arabia, where the rangelands are already under pressure from land use changes and population growth (Dregne, 1986). Substitution of the natural grazing lands by cropped forage will be difficult due to the expected reduction in water supply sources. Importation and supply of forage crops to nomads and rural communities will be very difficult. The welfare of these communities will be seriously threatened. Consequently the sustainability of economic development and the social structure in rural areas will be under serious challenges. Serious social impacts could occur, as millions will be forced out from their homelands as a result of desertification, poor harvests and water supply stresses. National economies would be adversely affected not only by the direct impacts of climate change, but also through the cost of adaptive measures and the knock-on implications of changes elsewhere. Quantitative estimates of financial costs are expected to suffer larger relative economic damages.

SAUDI ARABIA GREENHOUSE GASES REDUCTION POLICIES

Saudi Arabia is opposed to binding commitments in future climate negotiations and believes that only the industrialized countries that are already committed to emission reductions under the Kyoto Protocol should have future emissions targets. Saudi Arabia believes that developing countries should only have voluntary and non-specific commitments on greenhouse gas emissions (UNFCC 1997). Saudi Arabia points out that energy is necessary for economic and social development. Saudi Arabia is dependent on its oil and it believes that conversion to renewable energy sources would involve an unreasonable cost and would hinder the country's continued development. It argues that political decisions must support the two key requirements for sustainable development – social and economic development. You could also see this as each individual's right to development and hence, the right to a higher use of energy. The 2.4 billion people that today only have access to bio-fuel and lack modern energy for cooking and heating lack the very concept of reducing greenhouse gas emissions (Delmas *et al*., 1980). For these people, the daily focus is to fight their worst opponent: poverty (Korppoo, 2009). For the benefit of these people, the world's objective must be to make sure they have access to modern kinds of energy that are reliable, economically realistic, socially accepted and environmentally sound. This will not only raise their living standards, it will also help them to adapt to the unavoidable consequences of climate change.

A key element in the Saudi Arabian government's economic strategy is industrial diversification, a process that has as its primary objective the reduction of the Kingdom's dependence on oil revenues. To this end, the government has encouraged the development of a wide range of manufacturing industries. The government has provided a range of incentives to encourage the private sector to participate in the Kingdom's industrial effort. The Kingdom of Saudi Arabia ratified the UN Framework Convention on Climate Change in December 1994 (UNFCCC 2000). This convention aims to stabilize the greenhouse gas (GHG) concentrations in the atmosphere at a level that would prevent significant potential changes to the global climate (UNFCCC 2005) One effective option that has been adopted by various developed countries to obtain this objective is the stabilization of greenhouse gas emissions by the year 2000 at their 1990 levels. Being a signatory to the UNFCCC, Saudi Arabia has agreed to develop a national inventory of greenhouse gas emissions and sinks as part of its National Communication. The Intergovernmental Panel on Climate Change (IPCC, 1997) has standardized methodologies for the development of national inventories of greenhouse gases by the countries signatory to UNFCCC.

STUDY AREA

Jubail industrial city is located on the eastern coast of Saudi Arabia (Latitude: 27º 05' N; Longitude: 49º 35' E). Yanbu is approximately 350 kilometers north of Jeddah (Latitude: 24°05′N Longitude: 38°00′E). **Figure 2** and **3** shows the map Jubail and Yanbu industrial cities respectively. The prevailing wind direction in Jubail area mainly varies from WNW to NW with predominantly northwesterly winds. The monthly average wind speed varies from 2.5 to 4.8 m/s. The monthly average hourly air temperature varies from 15 to 37 ºC. The monthly average hourly relative humidity varies from 28 to 74%. The monthly average daily solar radiation for Jubail varies from 2,600 to 6,800 Wh/m^2/day. The meteorological parameters of Yanbu are similar to Jubail conditions.

Figure 2 Jubail industrial City.

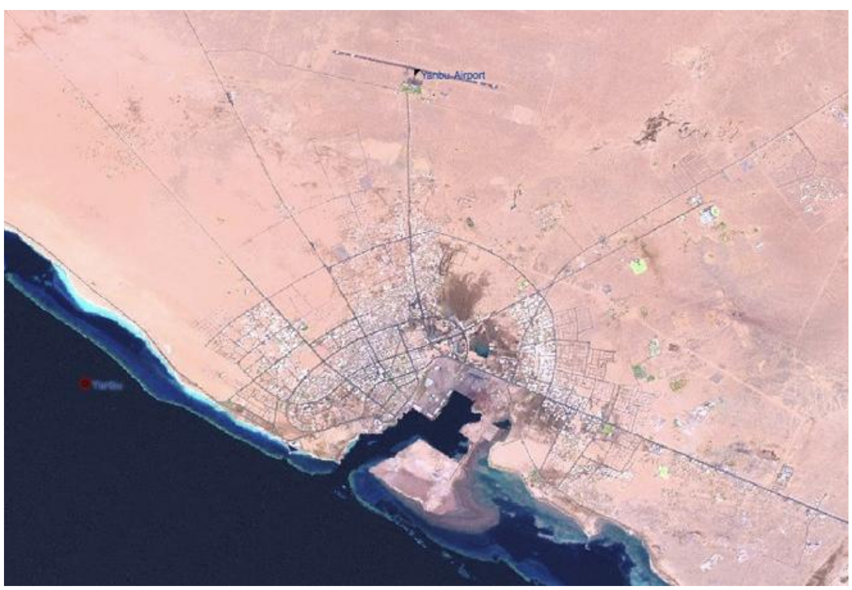

Figure 3 Yanbu industrial city

INDUSTRIAL CITY AT JUBAIL AND YANBU

The industrial cities at Jubail and Yanbu have played a key role in the Kingdom's determination to develop hydrocarbon-based and energy-intensive industries. The Royal Commission for Jubail and Yanbu, established by a Royal Decree, dated 21st September 1975 (16 Ramadan 1395 AH), created the basic infrastructure for these two cities, often described as the jewels in the Kingdom's industrial crown. By the end of the Third Development Plan (1405 AH: 1985), fifteen primary industrial projects (ten at Jubail and five at Yanbu) were operational. (RCJY 2012)

Jubail is the largest industrial city in the world and by 1999; it had more than 70,000 full-time residents, 17 basic industrial plants, 16 secondary industrial plants and 100 supporting and light industries plants, as well as a dedicated desalination plant, a vocational training institute and a college. By 2006, the number of full-time residents had increased to 94,100. Yanbu is a major industrial site with a modern port from which products manufactured locally and in other areas of the Kingdom are exported. By end of 1999, Yanbu had 72,740 full-time residents, eight basic industrial plants, eleven secondary industrial plants and 33 supporting and light industrial plants.

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RESEARCH OBJECTIVES

The main objectives of this research work, is to

- Estimate GHG emissions (CO_2, CH_4 and N_2O) from combustion facilities in RCJY.
- Formulate best fuel consumption scenarios based on the comparable GHG emissions of natural gas in case of short supply or total stoppage.
- Estimate of GHG emissions with alternative fuels.
- Ranking of fuel suitability.

IMPORTANCE OF THE STUDY

Increased use of fossil fuels as a result of rapid industrialization can be cited as one of the reasons of global warming. Increased international consciousness regarding the long-term implications of global warming has lead to international cooperation in the reduction of greenhouse gas emissions. In this context, it becomes extremely important to estimate the greenhouse gas emissions. Up to this moment, there are no independent small studies that examined the data submitted to the concerned agencies to test the adherence to international polices and treaties. For research purposes, there is a need for baseline studies and availability of declassified data for future estimation and also "what if" scenarios in the event of changing the natural gas supply to heavier oils.

CHAPTER TWO

LITERATURE REVIEW

This literature review of greenhouse gases emission from combustion facilities provides background reading to support the study of emissions from stationary combustion facilities and the nature of fuel type use. While many references have been utilized in this review, the IPCC report 2007 "Greenhouse Gas Inventory Workbook Revised IPCC 1996 Guidelines for National Greenhouse Gas Inventories. Volume 2" is a particularly important in general aspects of emission inventories and methodologies. Also, the "Saudi Arabian Second National Communication on greenhouse gases to UNFCCC 2008 and 2011" provided a valuable record of greenhouse gas emission inventories for Saudi Arabia. These and other more focused studies (Kone and Buke 2010; Mitra, *et al.* 2002; Zhang and Morawska 2002), have been most useful in developing the following structure and ideas including: The industrial cities at Jubail and Yanbu, Combustion sources, Estimation of greenhouse emissions, Fuel use and blending, Inherent limitations of field measurement and numerical modeling of greenhouse gases emissions.

Combustion sources can be classified into area or point sources, stationary or mobile sources and into outdoor or indoor sources (Moomaw, 1996). Outdoor combustion sources include stationary and mobile sources (Schwaiger and Schlamadinger 1998). Mobile sources are mainly motor vehicles, but also include aircraft and boats as well as small sources such as for example lawn mowers. Stationary sources are industrial plants, power plants, refineries, etc. The relative and absolute importance of these sources varies, and is a function of source strength, mixture of sources and population density in the vicinity of the sources and under ideal conditions, complete combustion of carbon would result only in generation of carbon dioxide (CO_2). Any products other than CO_2 are often called products of incomplete combustion and include particulate matter and gases. Gaseous emissions include inorganic and organic gases and vapors. The main gaseous emissions include carbon monoxide (CO), carbon dioxide (CO_2), nitrogen oxides (NOx), sulphur dioxide (SO_2), hydrocarbons (HC), and water vapour. (Moomaw (1996); Schwaiger and Schlamadinger 1998; Hayami and Nakamura 2007 Zhang and Morawska 2002).

Globally, the focus of emission studies is centered on the anthropogenic sources of carbon dioxide emission. There is a general consensus among environmentalist that the increases emission of CO_2 is responsible for noticeable changes in global climate. The high-accuracy measurements of atmospheric CO_2 concentration, initiated by Charles David Keeling in 1958, constitute the master time series, documenting the changing composition of the atmosphere (Keeling, *et al* 1976,; Àlvarez *et al.* 2003). These data have iconic status in climate change science as evidence of the effect of human activities on the chemical composition of the global atmosphere. Keeling's measurements on Mauna Loa in Hawaii provide a true measure of the global carbon cycle, an effectively continuous record of the burning of fossil fuel. They also maintain an accuracy and precision that allow scientists to separate fossil fuel emissions from those due to the natural annual cycle of the biosphere, demonstrating a long-term change in the seasonal exchange of CO_2 between the atmosphere, biosphere and ocean. Later observations of parallel trends in the atmospheric abundances of the $^{13}CO_2$ isotope

(Francey and Farquhar, 1982) and molecular oxygen (O_2) (Keeling and Shertz, 1992; Battle *et al*., 1996) uniquely identified this rise in CO_2 with fossil fuel burning (Figure 4).

To place the increase in CO_2 abundance since the late 1950s in perspective, and to compare the magnitude of the anthropogenic increase with natural cycles in the past, a longer-term record of CO_2 and other natural greenhouse gases is needed. These data came from analysis of the composition of air enclosed in bubbles in ice cores from Greenland and Antarctica. The initial measurements demonstrated that CO_2 abundances were significantly lower during the last ice age than over the last 10 yrs of the Holocene (Delmas *et al*., 1980; Berner *et al*., 1980; Neftel *et al*., 1982). From 10 yrs before present up to the year 1750, CO2 abundances stayed within the range 280 ± 20 ppm (Indermühle *et al*, 1999). During the industrial era, CO_2 abundance rose roughly exponentially to 367 ppm in 1999 (Neftel *et al*., 1985; Etheridge *et al*., 1996; IPCC, 2001a) and to 379 ppm in 2005. Direct atmospheric measurements since 1970 have also detected the increasing atmospheric abundances of two other major greenhouse gases, methane (CH_4) and nitrous oxide (N_2O). (Steele *et al*., 1996). Methane abundances were initially increasing at a rate of about 1% yr–1 (Graedel and McRae, 1980; Fraser *et al*., 1981; Blake *et al*., 1982) but then slowed to an average increase of 0.4% yr–1 over the 1990s with the possible stabilisation of CH_4 abundance (Dlugokencky *et al*., 1994).

The increase in N_2O abundance is smaller, about 0.25% yr–1, and more difficult to detect (Weiss, 1981; Khalil and Rasmussen, 1988). To go back in time, measurements were made from air trapped in snowpack dating back over 200 years, and these data show an accelerating rise in both CH_4 and N_2O into the 20th century (Machida *et al*., 1995). When ice core measurements extended the CH_4 abundance back 1 yr, they showed a stable, relatively constant abundance of 700 ppb until the 19th century when a steady increase brought CH_4

abundances to 1,745 ppb in 1998 and 1,774 ppb in 2005 (Battle *et al.*, 1996). This peak abundance is much higher than the range of 400 to 700 ppb seen over the last half-million years of glacial-interglacial cycles, and the increase can be readily explained by anthropogenic emissions. For N_2O the results are similar: the relative increase over the industrial era is smaller (15%), yet the 1998 abundance of 314 ppb, rising to 319 ppb in 2005, is also well above the 180-to-260 ppb range of glacial-interglacial cycles (Flückiger *et al.*, 1999)

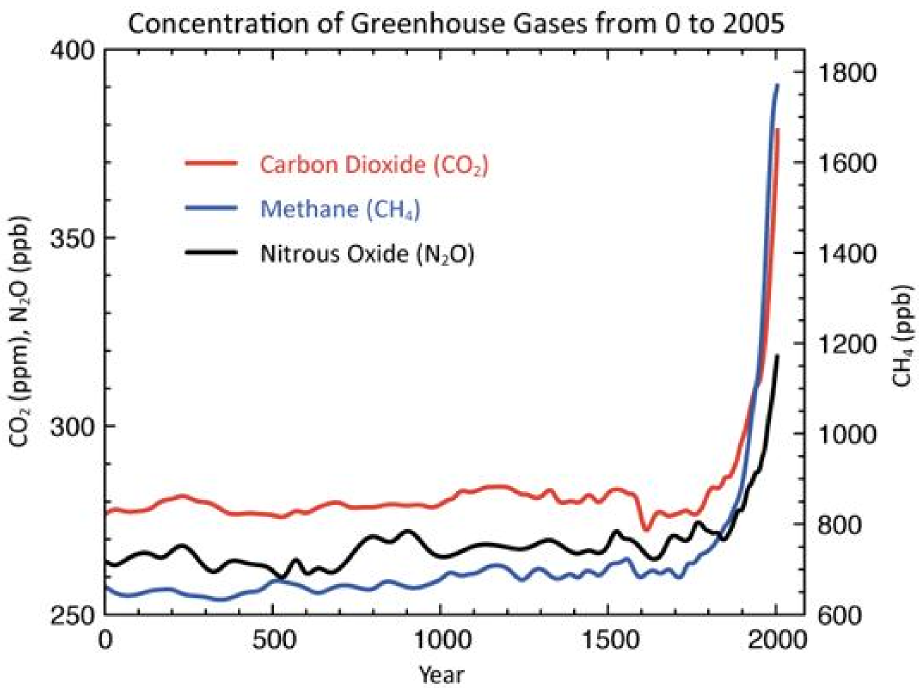


Figure 4 Atmospheric concentrations of important long-lived greenhouse gases over the last 2,000 years (Keeling and Shertz 1992)

The accelerating use of fossil fuels since the Industrial Revolution and the rapid destruction of forests cause a significant increase in greenhouse gases. The increasing threat of global warming and climate change has been the major, worldwide, ongoing concern especially in the last two decades. The impacts of global warming on the world economy have been assessed intensively by researchers since the 1990s. Worldwide organizations have been attempting to reduce the adverse impacts of global warming through intergovernmental and binding agreements. Carbon dioxide (CO_2) is one of the most foremost greenhouse gase in the atmosphere. The energy sector is dominated by the direct combustion of fuels, a process leading to large emissions of CO_2. CO_2 from energy represents about 60% of the anthropogenic greenhouse gas emissions of global emissions. This percentage varies greatly by country, due to diverse national energy structures. Aylin and Tayfun (2010) estimated that the top-25 emitting countries accounted for 82.27% of the world CO2 emissions in 2007.

CHAPTER THREE

METHODOLOGY

The 2006 IPCC Guidelines for National Greenhouse Gas Inventories (2006 Guidelines) were produced at the invitation of the United Nations Framework Convention on Climate Change (UNFCCC) to update the Revised 1996 Guidelines and associated good practice guidance which provide internationally agreed methodologies intended for use by countries and inventory compilers to estimate greenhouse gas inventories to reported to the UNFCCC.

In 1996, the Intergovernmental Panel on Climate Change (IPCC) accepted the Revised 1996 Guidelines for National Greenhouse Inventories and recommended that they were 'ready for use by Parties to the United Nations Framework Convention on Climate Change...' (Mexico City, 11-13 September 1996). The Subsidiary Body later adopted the Revised Guidelines for Scientific and Technological Advice (Geneva, 16-18 December 1996) and by the Conference of the Parties (Kyoto, 1-10 December 1997) under the United Nations Framework Convention on Climate Change. Recognizing that the Revised Guidelines are widely used by Parties to compile their national greenhouse gas inventories, the IPCC requested that the software for greenhouse gase be prepared. The software package used for the estimation (modeling) in this study was prepared by the IPCC Unit for Greenhouse Gas Inventories under Working Group I of the IPCC, in collaboration with the Organization for Economic Co-operation and Development (OECD) and the International Energy Agency (IEA) and adopted by the Royal Commission for Jubail and Yanbu to account for the nationwide emissions in the compilation of national greenhouse gas (GHG) inventory and in the preparation of their national UNFCC communication.

IPCC Guidelines for National Greenhouse Gas Inventories

The 2006 IPCC guidelines contain three volumes, which provide assistance to the analyst (complier) preparation of the greenhouse gases inventories. The volumes are:

The Reporting Instructions (Volume 1) provides step-by-step directions for assembling, documenting and transmitting completed national inventory data consistently, regardless of the method used to produce the estimates. These instructions are intended for all users of the IPCC Guidelines and provide the primary means of ensuring that all reports are consistent and comparable. (IPCC, 1997a)

The Workbook (Volume 2) contains suggestions about planning and getting started on a national inventory for participants who do not have a national inventory available already and are not experienced in producing such inventories. It also contains step-by-step instructions for calculating emissions of carbon dioxide (CO2) methane (CH4), nitrous oxide (N2O), halocarbons (HFCs, PFCs), Sulphur hexafluoride (SF6), ozone and aerosol precursors, from six major emission source categories. It is intended to help experts in as many countries as possible to start developing inventories and become active participants in the inventories program. The software used for the greenhouse gas estimation in this study is based on the contents of the workbook and was also developed by the IPCC. (IPCC, 1997b)

The Reference Manual (Volume 3) provides a compendium of information on methods for estimation of emissions for a broader range of greenhouse gases and a complete list of source types for each. It summarizes a range of possible methods for many source types. It also provides summaries of the scientific basis for the inventory methods recommended and gives extensive references to the technical literature. It is intended to help participants at all levels of experience to understand the processes, which cause greenhouse gas emissions and removals to occur and the estimation methods used in compiling inventories (IPCC, 1997c)

The *2006 IPCC Guidelines* allow for the use of a range of methods at different levels of detail, including methods, which are appropriate to national conditions. Default methods and assumptions are provided for calculating the major emissions and removals of greenhouse gases at the minimum acceptable level of detail. The IPCC default methods have been developed with efficiency in mind. They build on data that are readily available and should be easily applicable to all countries of the world

The *Guidelines* estimate carbon emissions in terms of the species, which are emitted. During the combustion process, most carbon is immediately emitted as CO_2. However, some carbon is released as carbon monoxide (CO), methane (CH_4) or non-methane volatile organic compounds (NMVOCs). Most of the carbon emitted as these non-CO_2 species eventually oxidises to CO_2 in the atmospheres. In the case of fuel combustion, the emissions of these non-CO_2 gases contain very small amounts of carbon compared to the CO_2 estimate. it is more accurate to base the CO_2 estimate on the total carbon in the fuel. This is because the total carbon in the fuel depends on the fuel alone, while the emissions of the non-CO_2 gases depend on many factors such as technologies, maintenance etc. which, in general, are not well known.

Inventory reporting

A greenhouse gas inventory report includes a set of standard reporting tables covering all relevant gases, categories and years, and a written report that documents the methodologies and data used to prepare the estimates. The 2006 Guidelines provide standardized reporting tables, but the actual nature and content of the tables and written report may vary according to, for example, a country's obligations as a Party to the UNFCCC. The 2006 Guidelines provide worksheets to assist with the transparent application of the most basic (or Tier 1) estimation methodology.

Greenhouse Gases

The following greenhouse gases, relevant to this study are covered in the 2006 Guidelines:

- carbon dioxide (CO_2)
- methane (CH_4)
- nitrous oxide (N_2O)

The gases listed above have global warming potentials (GWPs) identified by the IPCC prior to finalization of the 2006 Guidelines. A GWP compares the radiative forcing of a tonne of a greenhouse gas over a given time period (e.g., 100 years) to a tonne of CO_2. The 2006 Guidelines also provide information for the reporting of the following precursors: nitrogen oxides (NOx), ammonia (NH_3), non-methane volatile organic compounds (NMVOC), carbon monoxide (CO) and sulphur dioxide (SO_2).

Tiers: A tier represents a level of methodological complexity. Usually three tiers are provided. Tier 1 is the basic method, Tier 2 intermediate and Tier 3 most demanding in terms of complexity and data requirements. Tiers 2 and 3 are sometimes referred to as higher tier methods and are generally considered to be more accurate. In Saudi Arabia and this study, tier 1 is used for the estimation of greenhouse gases emissions.

- Tier 1: fuel combustion from national energy statistics and default emission factors;
- Tier 2: fuel combustion from national energy statistics, together with country-specific emission factors, where possible, derived from national fuel characteristics;
- Tier 3: fuel statistics and data on combustion technologies applied together with technology-specific emission factors; this includes the use of models and facility level emission data where available.

Default data: Tier 1 methods for all categories are designed to use readily available national or international statistics in combination with the provided default emission factors and additional parameters that are provided, and therefore should be feasible for all countries.

Key Categories: The concept of key category is used to identify the categories that have a significant influence on a country's total inventory of greenhouse gases in terms of the absolute level of emissions and removals, the trend in emissions and removals, or uncertainty in emissions and removals. Key Categories should be the priority for countries during inventory resource allocation for data collection, compilation, quality assurance/quality control and reporting.

This section describes the methods and data necessary to estimate emissions from Stationary Combustion facilities based on IPCC guidelines (2006) (Appendix 1). Generally, there are three methods (Tiers) described for the estimation of GHG, but the scope of this work covers two methodologies, which is accurate enough. The result is evaluated based on the amount of fuel consumed, type of fuel, efficiency of combustion, technology used for combustion etc.

The following methods (tiers) where selected

- Tier 1: involves fuel combustion from national energy statistics and default emission factors; while
- Tier 2: involves fuel combustion from national energy statistics, together with country-specific emission factors, where possible, derived from national fuel characteristics;

CONCEPTS

Inventories rely on a few key concepts for which there are a common understanding. This helps ensure that inventories are comparable between countries, do not contain double counting or emissions, and that the time series reflect actual changes in emissions.

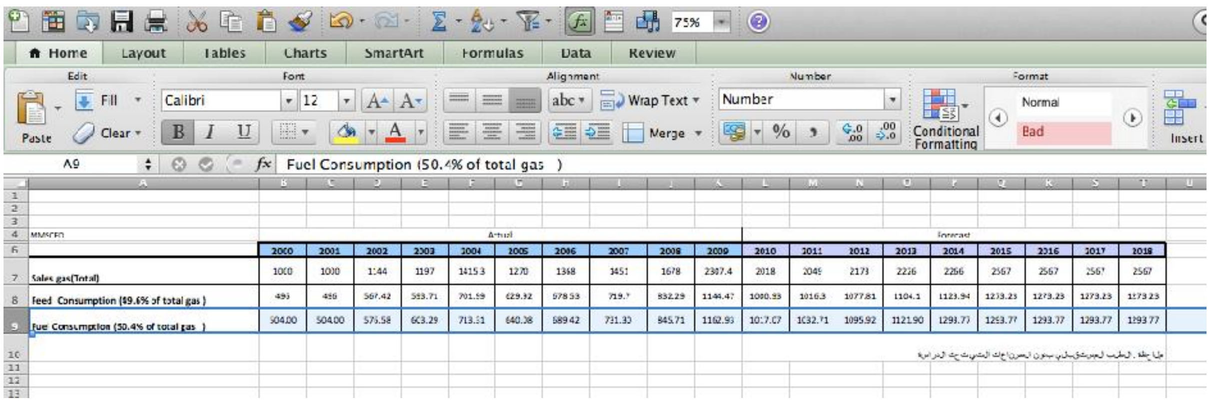
Inventory Year and time series

National inventories contain estimates for the calendar year during which the emissions to (or removals from) the atmosphere occur. Where suitable data to follow this principle are missing, emissions/removals may be estimated using data from other years applying appropriate methods such as averaging, interpolation and extrapolation. A sequence of annual greenhouse gas inventory estimates (e.g., each year from 1990 to 2000) is called a time series.

SOURCE OF DATA

The fuel consumption data used for this study was collected from annual technical reports that are developed at the planning departments of Royal Commission for Jubail and Yanbu.

The data represent the total amount of natural gas used in combustion facilities for petrochemical companies within the two industrial cities. The data were expressed in million standard cubic feet (MMSCF) starting from year 2000 to 2017. The values from 2012 to 2017 are predicted values supplied by RC based on its knowledge of the two industrial cities fuel consumption trends. The natural gas amounts were divided into feedstock and combusted fuel in the ratio of 49.6:50.4 (**Figure 5**) as indicated by Royal Commission. Using the natural gas density value provided by SABIC, the amounts where later expressed in tons (metric units used by the IPCC guidelines in the software).



MMSCFD	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Sales gas(Total)	1000	1000	1144	1197	1415.3	1270	1368	1451	1678	2307.4
Feed Consumption (49.6% of total gas)	495	496	567.42	593.71	701.99	629.92	578.53	719.7	832.29	1144.47
Fuel Consumption (50.4% of total gas)	504.00	504.00	575.58	603.29	713.31	640.08	589.42	731.30	845.71	1162.93

MMSCFD	2010	2011	2012	2013	2014	2015	2016	2017	2018
Sales gas(Total)	2018	2049	2173	2226	2266	2567	2567	2567	2567
Feed Consumption (49.6% of total gas)	1000.93	1016.3	1077.81	1104.1	1123.94	1273.23	1273.23	1273.23	1273.23
Fuel Consumption (50.4% of total gas)	1017.07	1032.71	1095.92	1121.90	1293.77	1293.77	1293.77	1293.77	1293.77

Figure 5 Fuel consumption data supplied by RC J&Y

CALCULATION AND TABULATION OF DATA

Emissions of each greenhouse gas from stationary sources are calculated by multiplying fuel consumption by the corresponding emission factor (**Equation 1 below**). In this Approach, "Fuel Consumption" is estimated from energy use statistics and is measured in **terajoules**. Fuel consumption data in mass or volume units are first be converted into the energy content of these fuels. The tier one (1) approach used in this study described below use the amount of fuel combusted as the primary activity data. The quantity of energy from the combustion of known amount of Natural gas was determine by the equation

$$Energy\ content(Tj) = NCV\ \left(\frac{Tj}{1000\ tons}\right) \times quantity\ \ of\ Natural\ Gas\ per\ yr\ (tons)$$

Where : NCV= Net calorific Value and it is specific and unique for each fuel.

The quantity of each fuel was obtained by dividing the

$$Quantity\ \ of\ other\ fuel\ per\ yr\ (tons) = \frac{Energy\ content(Tj)}{NCV\ \left(\frac{Tj}{1000\ tons}\right)}$$

The equations are already programmed in IPCC (2006) guideline workbook **(Figure 6)**

TIER ONE APPROACH USED

Applying a Tier 1 emission estimate requires the following for each source category and fuel:

• Data on the amount of fuel combusted in the source category

• A default emission factor (**Table 1**); Emission factors come from the default values provided together with associated uncertainty range by IPCC.

Equation 1.

$$\boldsymbol{Emissions_{GHG,\ fuel} = Fuel\ Consumption_{fuel} * Emission\ Factor_{GHG,\ fuel}}$$

Where:

- Emissions $_{GHG,fuel}$ = emissions of a given GHG by type of fuel (kg GHG)
- Fuel Consumption $_{fuel}$ = amount of fuel combusted (TJ)
- Emission Factor $_{GHG,\ fuel}$ = default emission factor of a given GHG by type of fuel (kg gas/TJ). For CO2 it includes the carbon oxidation factor, assumed to be 1.

Table 1 Summarize the default IPCC emission factors for different types of fuels adopted by Saudi Arabia and used in this study.

CO_2 Emission		**CH_4 Emission**		**N_2O Emission**	
Type of fuel	Carbon emission factor (ton of C/Tj)	Type of fuel	Emission factor (kg/Tj)	Type of fuel	Emission factor (kg/Tj)
Crude Oil	20	Crude Oil	3	Crude Oil	0.6
Diesel Oil	20.2	Diesel Oil	3	Diesel Oil	0.6
Gasoline	18.9	Gasoline	20	Gasoline	0.6
Fuel Gas	20.2	Fuel Gas	1	Fuel Gas	0.1
Fuel Oil	21.1	Fuel Oil	3	Fuel Oil	0.6
Natural Gas	15.3	Natural Gas	1	Natural Gas	0.1
Ethane Gas	16.8	Ethane Gas	1	Ethane Gas	0.1
Liquefied Petroleum Gas	17.2	Liquefied Petroleum Gas	1	Liquefied Petroleum Gas	0.1
Natural Gas Liquid	17.2	Natural Gas Liquid	1	Natural Gas Liquid	0.1

The quality of these emission factors differs between gases. For CO_2, emission factors mainly depend upon the carbon content of the fuel. Combustion conditions (combustion efficiency, carbon retained in slag etc.) are relatively unimportant. Therefore, CO_2 emissions can be estimated accurately based on the total amount of fuels combusted and the averaged carbon content of the fuels using Tier 1 method. However, emission factors for methane and nitrous oxide depend on the combustion technology and operating conditions and vary significantly, both between individual combustion installations and over time. Due to this variability, use of averaged emission factors for these gases, which must account for a large variability in technological conditions, will introduce relatively large uncertainties.

UNCERTAINTIES IN EMISSIONS ESTIMATION

Due to the unavailability of certain source specific input data including emission factors, uncertainties are unavoidable when any estimate of national emissions or removals is made. It is therefore important to establish and express uncertainties quantitatively and/or with the acceptable confidence interval or range. The 2006 IPCC Guidelines provide a general table for relative uncertainties associated with emission factors and activity data, which is limited to CO_2, CH_4 and N_2O emissions only. Uncertainties in emissions estimation basically comes from two major sources: input data and the assumptions used in selecting the emission factors, and adopting extrapolated and/or averaged values in calculations.

Uncertainties related to input data depend mainly on the size and quality of data collection and record keeping. Uncertainties involved in selection of emission factors comes from the fact that the default values provided in the IPCC Guidelines (1997) were established for a certain group of activities that comprises a number of processes. The nature of a group of activity in a particular country may differ from the generalized nature of the group considered in derivation/establishment of the default emission factors. Similar analogy applies to the variation in source and/or sink characteristics in different countries. Therefore, the default emission factors may not exactly represent and characterize the actual conditions of source/sink activities. Non-Annex-I countries (primarily developing countries) do not have binding targets under the Kyoto Protocol, but must ratify the Protocol in order to be hosting Clean Development Mechanism projects. Saudi Arabia is a Non-Annex I country as such adopted the Tier 1 approach to estimate its greenhouse gas emissions.

Input Data

The raw data provided by the government organizations were considered to be accurate. The uncertainties involved in estimation of missing data were not *quantified* since it was not possible to establish uncertainty levels associated with the extrapolated and/or averaged values adopted in emissions calculations.

Emission Factors

The uncertainties associated with the emission factors used in this study were taken from the IPCC Guidelines (1997) and ranged between 5 and 10%.

Overall Emissions Estimation

The overall uncertainty of CO_2 and CH_4 emissions were estimated according to the IPCC Guidelines (1997). Uncertainties in emission estimates for other greenhouse gases were not determined due to the unavailability of relevant data, and/or methodology in the IPCC Guidelines.

Statistical Analysis

Krustal-Wallis One Way Analysis of Variance on Ranks, which is a function of the statistical package 'SIGMA PLOT 11' was applied to check for significant differences between the scenarios. Tukey's pairwise comparison method was used to rank the scenarios for suitability as substitute fuel .

The Tukey Test is computed based on a mathematical model of the probability structure of the multiple comparisons. The Tukey Test is more conservative than the Student-Newman-Keuls test, because it controls the errors of all comparisons simultaneously, while the Student-Newman-Keuls test controls errors among tests of k means. Because it is more conservative, it is less likely to determine that a give differences is statistically significant and it is the recommended test for all pairwise comparisons.

CHAPTER 4

RESULTS AND DISCUSSION

EMISSION SCENARIOS OF DIRECT GREENHOUSE GASES (CO2, CH4, N2O) FOR PURE FUELS (JUBAIL)

Scenario 1 – 100% Natural Gas use (Normal Case)

The normal case is characterized to use 100 % of natural gas (NG) for all the combustion facilities. Since the NG is the cleanest fuel, the lowest emissions are expected as compared to other fuel. The estimated greenhouse gas (GHG) emissions for CO_2, CH_4 and N_2O and fuel consumption are illustrated in **Table 2** and **Figure 6** for the years from 2000 to 2012. It was found that the highest CO_2, CH_4 and N_2O emissions from the actual fuel consumption data were 23,840 Gg (2009), 427 tons (2009) and 43 tons (2009) respectively. The lowest CO_2, CH_4 and N_2O emissions were obtained as 10331 Gg (2000-2001), 185 tons (2000-2001), 19 tons (2000-2001), respectively. The trend analysis shows that since the fuel consumption is proportionally related to the emissions, there is a constants increment with occasional drops as witnessed in 2005, 2010 and 2011. This scenario forms the basis for comparison for all other fuel consumption scenarios.

Table 2 Scenario 1 – 100% Natural Gas use (Normal Case)

Year	Fuel (tons)	CO_2 (Gg)	CH_4(tons)	N_2O (tons)
2000	4271517	10331	185.1	19
2001	4271517	10331	185.1	19
2002	4890209	11828	211.9	21
2003	5110565	12361	221.4	22
2004	6042840.5	14616	261.8	26
2005	5424148.6	13119	235	24
2006	5839435	14124	253	25
2007	6195394.7	14985	268	27
2008	7170046.4	17342	310.7	31
2009	9856695	23840	427.1	43
2010	8619311.1	20847	373.5	37
2011	8754914.8	21175	379.4	38
2012	9288854.5	22467	402.5	40

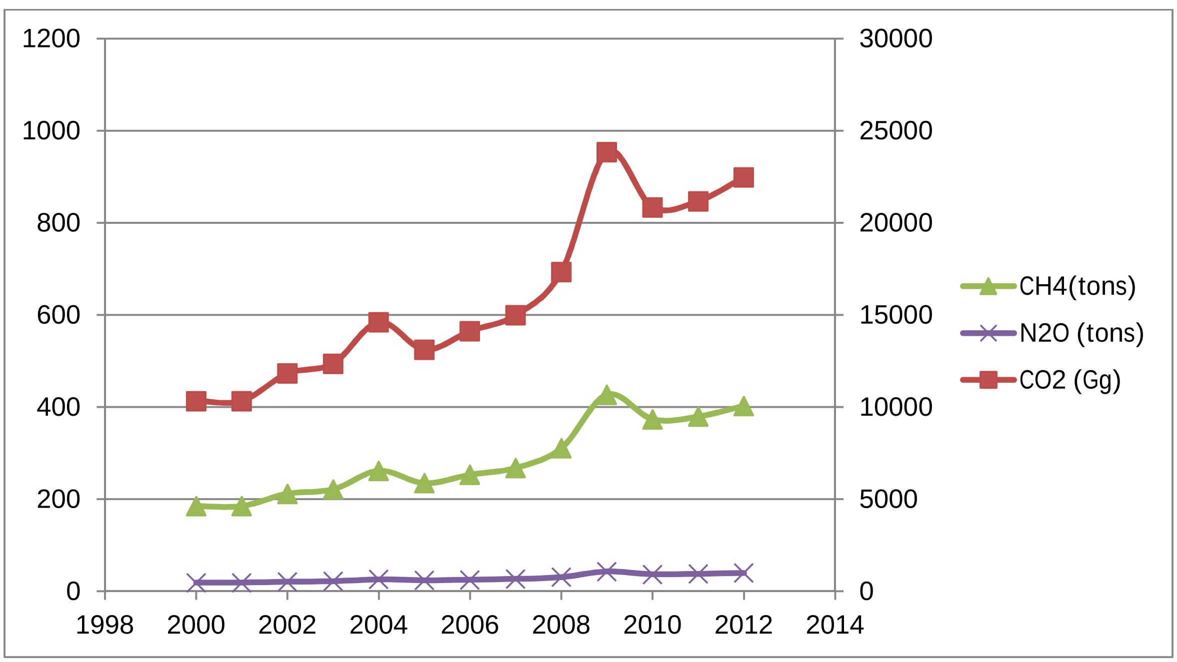


Figure 6 Scenario 1 - Greenhouse gas emissions for CO_2, CH_4 and N_20 (Jubail)

Scenario 2 – 100% Crude Oil use

Saudi Arabia has one-fifth of the world's proven oil reserves, and maintains the world's largest oil production capacity. For more than a decade, Saudi Aramco, the world's seventh largest natural gas producer, has aggressively explored for additional reserves to meet growing demand, although success has been limited. There is a growing need for a substitute fuels to be used in different sector currently depending on 100% supply of natural gas in case of future shortages. The Crude oil Scenario is characterized to use 100 % Crude oil (CRO). Since Saudi Arabia has the largest reserves of Crude, this may result in future reliance to meet the nation energy requirement, due to its low need for further processing, cost and abundance. The estimated greenhouse gas (GHG) emissions for CO_2, CH_4 and N_2O and fuel consumption are illustrated in **Table 3** and **Figure 7** for the years from 2000 to 2012. It was found that the highest CO_2, CH_4 and N_2O emissions from the actual fuel consumption data were 31,007 Gg (2009), 1281 tons (2009) and 256 tons (2009) respectively. The lowest CO_2, CH_4 and N_2O emissions were obtained as 13,437 Gg (2000-2001), 555 tons (2000-2001), 111 tons (2000-2001), respectively. The trend analysis shows that as compared to naturals gas emission values, crude oil will produce very high emissions hence might not be a good substitute fuel. Also, there is a remarkable level of SO2 emissions from the usage of crude oil that will generate similar energy to natural gas. SO_2 emission has been implicated in several health related conditions. From the analysis above, it is evident that the government (Saudi Arabia) needs to work toward reducing the reliance on the usage of this option due to the severity of it impacts on human health and environment.

Table 3 Scenario 2- 100% Crude Oil.

Year	Fuel (tons)	CO2 (Gg)	CH4 (tons)	N2O (tons)
2000	4350842	13437	555.3	111.1
2001	4350842	13437	555.3	111.1
2002	4981025	15383	635.7	127.7
2003	5205472	16077	664.3	132.9
2004	6155061	19009	785.5	157.1
2005	5524888	17063	705.1	141
2006	5947877	18369	759.1	151.8
2007	6310494	19489	805.3	161.1
2008	7303199	20555	932	186.4
2009	10039741	31007	1281.3	256.3
2010	8779379	27114	1120.4	224.1
2011	8917501	27541	1138.1	227.6
2012	9461356	29220	1207.5	241.5

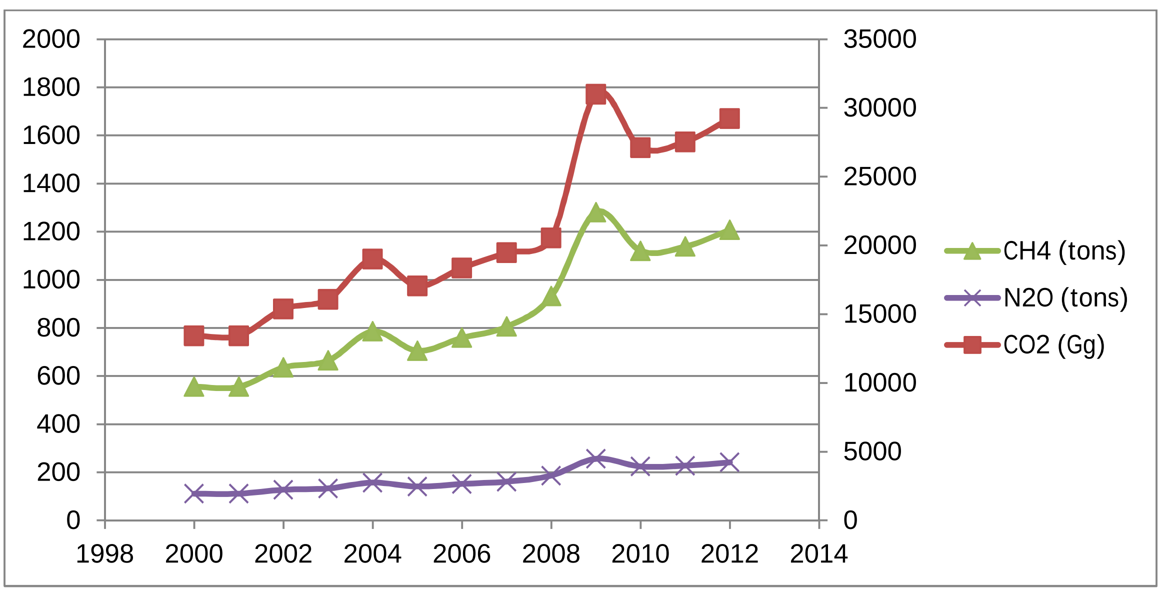


Figure 7 Scenario 2 - Greenhouse gas emissions for CO_2, CH_4 and N_20 (Jubail)

Scenario 3 – 100% Diesel Fuel use

Diesel is increasingly being developed and adopted in most industrial settings within Saudi Arabia due to its substantially lowered sulfur contents as compared to crude oil and fuel oil. The estimated greenhouse gas (GHG) emissions for CO_2, CH_4 and N_2O and fuel consumption are illustrated in **Table 4** and **Figure 8** for the years from 2000 to 2012. It was found that the highest CO_2, CH_4 and N_2O emissions from the actual fuel consumption data were 31317 Gg (2009), 1281 tons (2009) and 256 tons (2009) respectively. While the forecasted data yielded 34,844 Gg (2014-2017), 1426 tons (2014-2017), 285 tons (2014-2017), respectively and the lowest CO_2, CH_4 and N_2O emissions were obtained as 13572 Gg (2000-2001), 555 tons (2000-2001), 111 tons (2000-2001), respectively. The trend analysis shows that Diesel produces a 30% increment in CO_2 emissions over the use of natural gas when the highest actual consumption value considered and has a lower SO_2 emission as compared with the usage of crude oil (51% decrease). Hence, the diesel scenario is a prospective candidate for the fuel substitute.

Table 4 Scenario 3 - 100% Diesel.

Year	Fuel (tons)	CO_2 (Gg)	CH_4 (tons)	N_2O (tons)
2000	4,271,516	13572	555	111
2001	4,271,516	13572	555	111
2002	4,890,111	15537	636	127
2003	5,110,565	16237	664	133
2004	6,042,836	19199	786	157
2005	5,424,150	17234	708	141
2006	5,839,435	18553	759	152
2007	6,195,396	19684	805	161
2008	7,170,046	22781	932	186
2009	9,856,695	31317	1281	256
2010	8,619,312	27385	1120	224
2011	8,754,916	27816	1138	228
2012	9,288,855	29513	1208	242

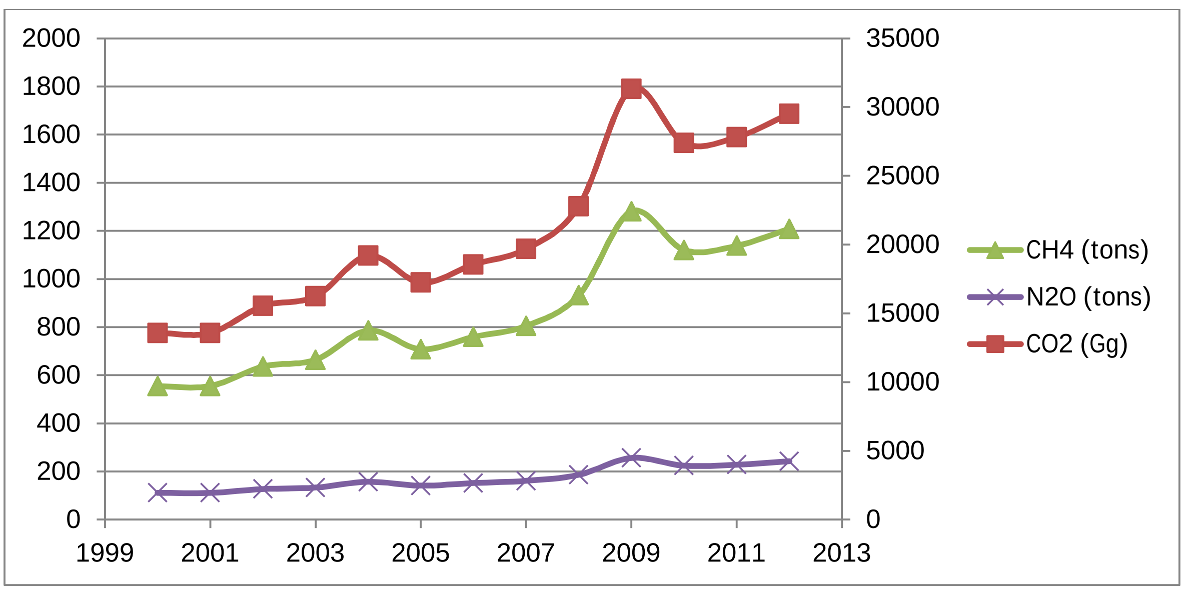


Figure 8 Scenario 3 - Greenhouse gas emissions for CO_2, CH_4 and N_20 (Jubail)

Scenario 4 – 100% Fuel Oil use

The term fuel oil in a stricter sense, refer only to the heaviest commercial fuel that can be obtained from crude oil heavier than gasoline and naphtha. Fuel oil can be used for power generation; hence there is the possibility of reliance in the usage of this fuel type in the event of shortages of natural gas. The estimated greenhouse gas (GHG) emissions for CO_2, CH_4 N_2O and fuel consumption are illustrated in **Table 5** and **Figure 9** for the years from 2000 to 2012. It was found that the highest CO_2, CH_4 and N_2O emissions from the actual fuel consumption data were 32612 Gg (2009), 1281 tons (2009) and 256 tons (2009) respectively. The lowest CO_2, CH_4 and N_2O emissions were obtained as 14176 Gg (2000-2001), 555 tons (2000-2001), 111 tons (2000-2001), respectively. The trend analysis shows that Fuel oil produces a 37% increment in CO_2 emissions over the use of natural gas when the highest actual consumption value is considered.

Table 5 Scenario 4 - 100% Fuel Oil.

Year	Fuel (tons)	CO_2 (Gg)	CH_4 (tons)	N_2O (tons)
2000	4,605,245	14,176	555	111.1
2001	4,605,245	14,176	555	111.1
2002	5,272,277	16,230	636	127.1
2003	5,261,030	16,195	634	126.9
2004	6,514,961	20,055	786	157.1
2005	5,270,167	16,223	635	127.1
2006	6,295,663	19,380	759	151.8
2007	6,679,435	20,561	805	161.1
2008	7,730,234	23,796	932	186.4
2009	10,626,788	32,612	1,281	256.3
2010	9,292,730	28,606	1,120	224.1
2011	9,438,928	29,056	1,138	227.6
2012	10,014,583	30,828	1,208	241.5

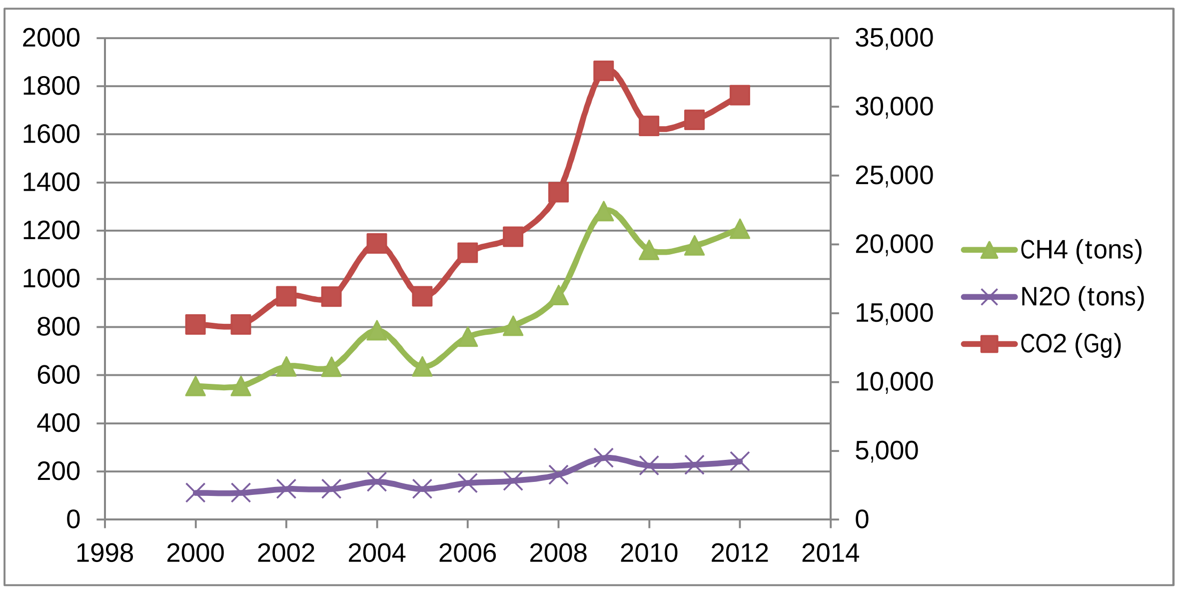


Figure 9 Scenario 4 - Greenhouse gas emissions for CO_2, CH_4 and N_20 (Jubail)

EMISSION SCENARIOS OF DIRECT GREENHOUSE WITH BLENDED FUELS

Scenario 5 – 50% Natural Gas and 50% Crude Oil Use.

The estimated greenhouse gas (GHG) emissions for CO_2, C§H_4 and N_2O and fuel consumption are illustrated in **Table 6** and **Figure 10** for the years from 2000 to 2012. It was found that the highest CO_2, CH_4 and N_2O emissions from the actual fuel consumption data were 27,423 Gg (2009), 854 tons (2009) and 150 tons (2009) respectively. The lowest CO_2, CH_4 and N_2O emissions were obtained as 11884 Gg (2000-2001), 370 tons (2000-2001), 65 tons (2000-2001), respectively. The trend analysis shows that there is a 15 % more emission of CO_2 when the highest values of actual natural usage were compared with this scenario; hence this blend is a good reasonably acceptable within a 20% window of acceptance.

Table 6 Scenario 5 - 50% Natural gas and 50% Crude Oil.

YEAR	50% NG	50% Crude oil	CO_2 (Gg)	CH_4 (tons)	N_2O (tons)
2000	2135758.5	2175421	11884	370	65
2001	2135758.5	2175421	11884	370	65
2002	2445104.5	2490512.5	13606	424	74
2003	2555282.5	2602736	14219	443	78
2004	3021420.3	3077530.5	16812	524	92
2005	2712074.3	2762444	15091	470	82
2006	2919717.5	2973938.5	16247	506	89
2007	3097697.4	3155247	17237	537	94
2008	3585023.2	3651599.5	19949	521	109
2009	4928347.5	5019870.5	27423	854	150
2010	4309655.6	4389689.5	23981	747	131
2011	4377457.4	4458750.5	24358	759	133
2012	4644427.2	4730678	25844	805	141

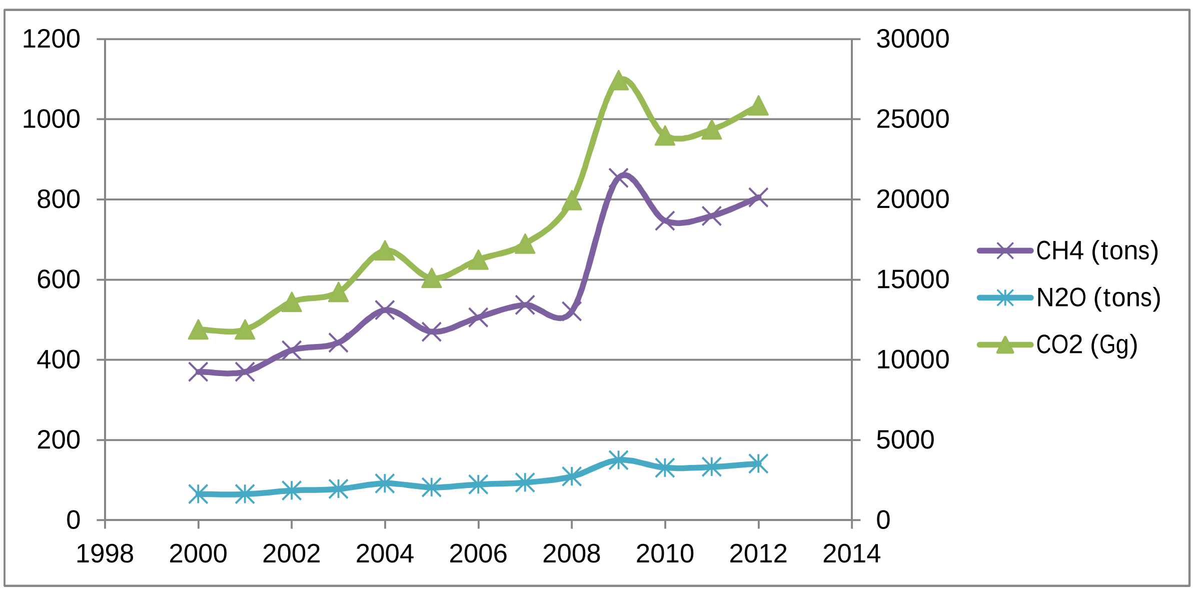


Figure 10 Scenario 5 - Greenhouse gas emissions for CO_2, CH_4 and N_20 (Jubail)

Scenario 6 – 70% Natural Gas and 30% Crude Oil Use.

The estimated greenhouse gas (GHG) emissions for CO_2, CH_4 and N_2O and fuel consumption are illustrated in **Table 7** and **Figure 11** for the years from 2000 to 2012. It was found that the highest CO_2, CH_4 and N_2O emissions from the actual fuel consumption data were 25,990 Gg (2009), 683 tons (2009) and 107 tons (2009) respectively. The lowest CO_2, CH_4 and N_2O emissions were obtained as 11263 Gg (2000-2001), 296 tons (2000-2001), 46 tons (2000-2001), respectively. The trend analysis shows that there is a 9 % more emission of CO_2 when the highest values of actual natural usage were compared with this scenario; hence this blend is a reasonably acceptable within a 20% window of acceptance.

Table 7 Scenario 6 - 70% Natural gas and 30% Crude Oil.

YEAR	70% NG	30% Crude oil	CO_2 (Gg)	CH_4 (tons)	N_2O (tons)
2000	2,990,062	1,305,253	11,263	296	46
2001	2,990,062	1,305,253	11,263	296	46
2002	3,423,146	1,494,308	12,894	339	53
2003	3,577,396	1,561,642	13,475	354	55
2004	4,229,988	1,846,518	15,934	419	66
2005	3,796,904	1,657,466	14,302	376	59
2006	4,087,604	1,784,363	15,397	405	63
2007	4,336,776	1,893,148	16,336	430	67
2008	5,019,032	2,190,960	18,906	497	78
2009	6,899,687	3,011,922	25,990	683	110
2010	6,033,518	2,633,814	22,727	598	93
2011	6,128,440	2,675,250	23,085	607	95
2012	6,502,198	2,838,407	24,493	644	100

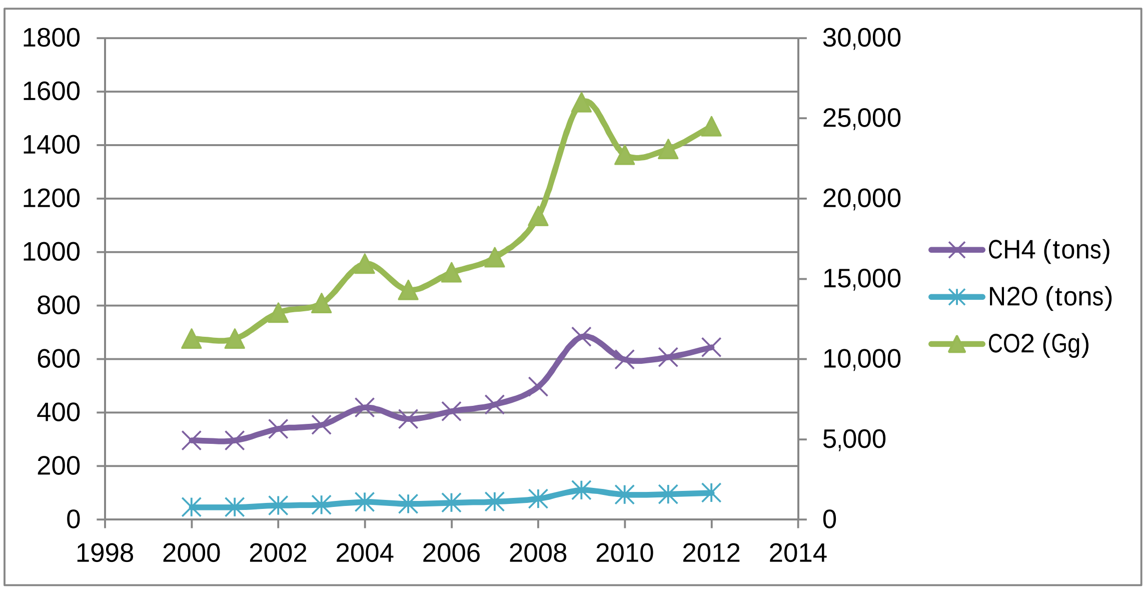


Figure 11 Scenario 6 - Greenhouse gas emissions for CO_2, CH_4 and N_20 (Jubail)

Scenario 7 – 50% Natural Gas and 50% Diesel Use.

The estimated greenhouse gas (GHG) emissions for CO_2, CH_4 and N_2O and fuel consumption are illustrated in **Table 8** and **Figure 12** for the years from 2000 to 2012. It was found that the highest CO_2, CH_4 and N_2O emissions from the actual fuel consumption data were 27,578 Gg (2009), 854 tons (2009) and 150 tons (2009) respectively. The lowest CO_2, CH_4 and N_2O emissions were obtained as 11951 Gg (2000-2001), 370 tons (2000-2001), 65 tons (2000-2001), respectively. The trend analysis shows that there is a 16 % more emission of CO_2 when the highest values of actual natural usage were compared with this scenario; hence this blend is a reasonably acceptable within a 20% window of acceptance.

Table 8 Scenario 7 - 50% Natural gas and 50% Diesel Oil.

YEAR	50% NG	50% Diesel	CO_2 (Gg)	CH_4 (tons)	N_2O (tons)
2000	2135758.5	2135758	11951	370	65
2001	2135758.5	2135758	11951	370	65
2002	2445104.5	2445055.5	13682	439	84
2003	2555282.5	2555282.5	14299	443	77
2004	3021420.3	3021418	16907	554	92
2005	2712074.3	2712075	15176	470	82
2006	2919717.5	2919717.5	16338	506	89
2007	3097697.4	3097698	17334	537	94
2008	3585023.2	3585023	20061	621	109
2009	4928347.5	4928347.5	27578	854	150
2010	4309655.6	4309656	24116	747	131
2011	4377457.4	4377458	24496	759	133
2012	4644427.2	4644427.5	25990	855	141

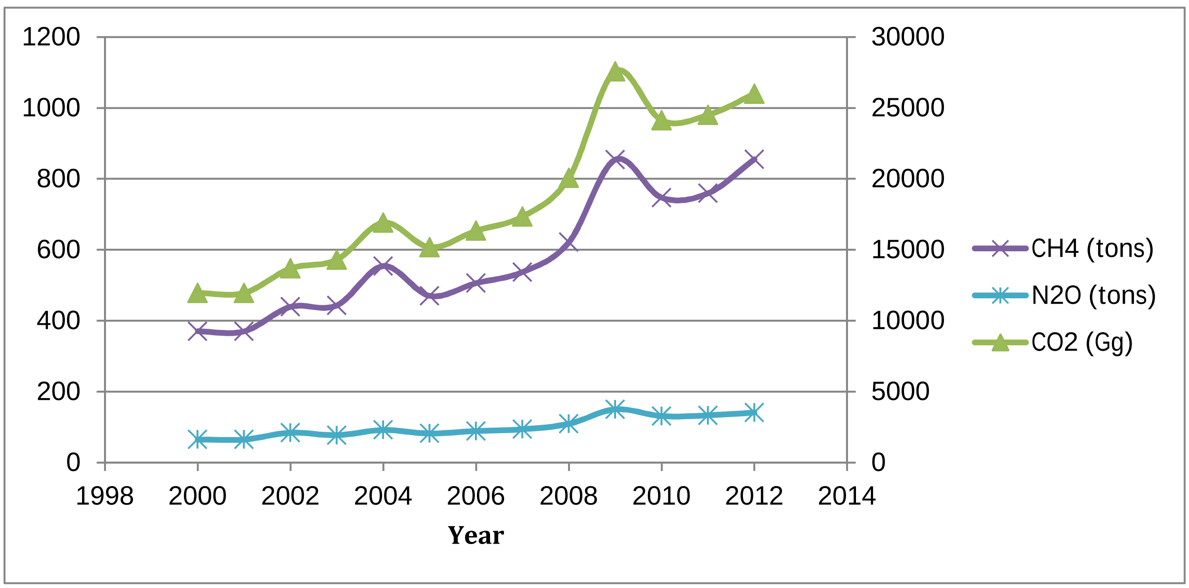


Figure 12 Scenario 7- Greenhouse gas emissions for CO_2, CH_4 and N_20 (Jubail)

Scenario 8 – 70% Natural Gas and 30% Diesel Use.

The estimated greenhouse gas (GHG) emissions for CO_2, CH_4 and N_2O and fuel consumption are illustrated in **Table 9** and **Figure 13** for the years from 2000 to 2012. It was found that the highest CO_2, CH_4 and N_2O emissions from the actual fuel consumption data were 26,083 Gg (2009), 683 tons (2009) and 107 tons (2009) respectively. The lowest CO_2, CH_4 and N_2O emissions were obtained as 11303 Gg (2000-2001), 296 tons (2000-2001), 46 tons (2000-2001), respectively. The trend analysis shows that there is a 9 % more emission of CO_2 when the highest values of actual natural usage were compared with this scenario; hence this blend is a reasonably acceptable within a 20% window of acceptance.

Table 9 Scenario 8 - 70% Natural gas and 30% Diesel Oil

YEAR	70% NG	30% Diesel	CO_2 (Gg)	CH_4 (tons)	N_2O (tons)
2000	2990061.9	1281454.8	11303	296	46
2001	2990061.9	1281454.8	11303	296	46
2002	3423146.3	1467033.3	12941	339	53
2003	3577395.5	1533169.5	13542	359	55
2004	4229988.4	1812850.8	15991	419	66
2005	3796904	1627245	14354	376	59
2006	4087604.5	1751830.5	15452	405	63
2007	4336776.3	1858618.8	16394	430	67
2008	5019032.5	2151013.8	18974	497	78
2009	6899686.5	2957008.5	26083	683	107
2010	6033517.8	2585793.6	22809	598	93
2011	6128440.4	2626474.8	23167	607	95
2012	6502198.1	2786656.5	24580	644	101

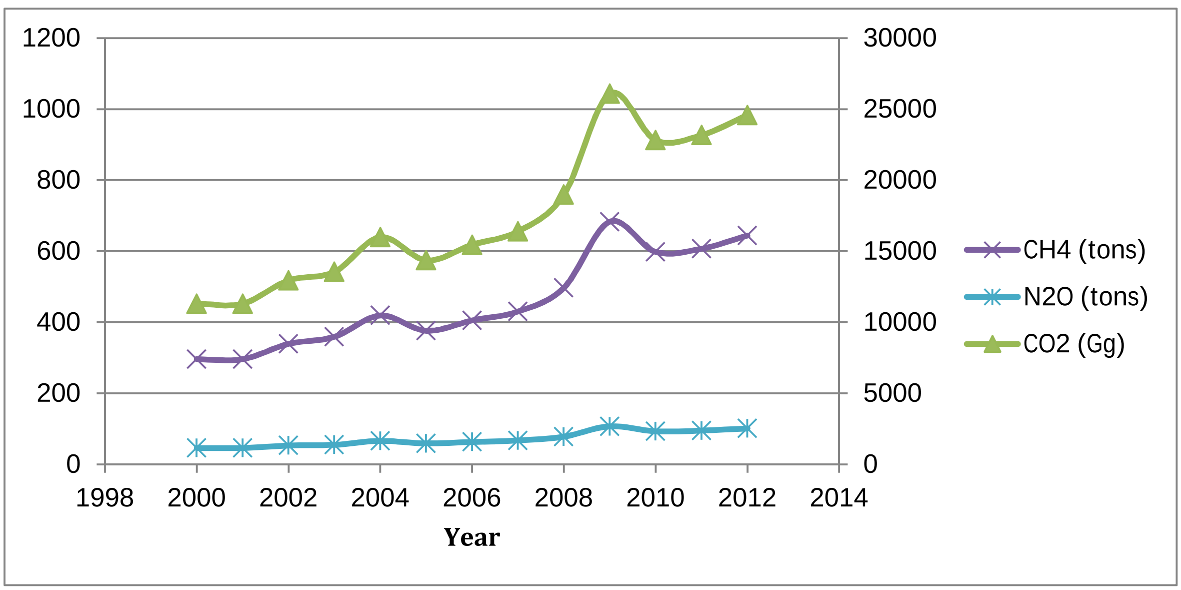


Figure 13 Scenario 8- Greenhouse gas emissions for CO_2, CH_4 and N_20 (Jubail)

Scenario 9 – 50% Natural Gas and 50% Fuel Oil.

The estimated greenhouse gas (GHG) emissions for CO2, CH4 and N2O and fuel consumption are illustrated in **Table 10** and **Figure 14** for the years from 2000 to 2012. It was found that the highest CO_2, CH_4 and N_2O emissions from the actual fuel consumption data were 28,2760 Gg (2009), 854 tons (2009) and 149 tons (2009) respectively. The lowest CO_2, CH_4 and N_2O emissions were obtained as 12254 Gg (2000-2001), 370 tons (2000-2001), 65 tons (2000-2001), respectively. The trend analysis shows that there is a 19 % more emission of CO_2 when the highest values of actual natural usage were compared with this scenario; hence this blend is a reasonably acceptable within a 20% window of acceptance.

Table 10 Scenario 9 - 50% Natural gas and 50% Fuel Oil

YEAR	50% NG	50% FUEL OIL	CO_2 (Gg)	CH_4 (tons)	N_2O (tons)
2000	2135759	2302623	12254	370	65
2001	2135759	2302613	12254	370	65
2002	2445104	2636138	14029	424	74
2003	2555283	2630515	14278	428	75
2004	3021420	3257481	17335	524	92
2005	2712074	2635083	14271	435	75
2006	2919717	3147832	16752	506	89
2007	3097697	3339718	17773	537	94
2008	3585023	3865117	20569	621	109
2009	4928348	5313394	28276	854	149
2010	4309656	4646365	24726	747	131
2011	4377457	4719464	25115	759	133
2012	4644427	5007292	26647	805	141

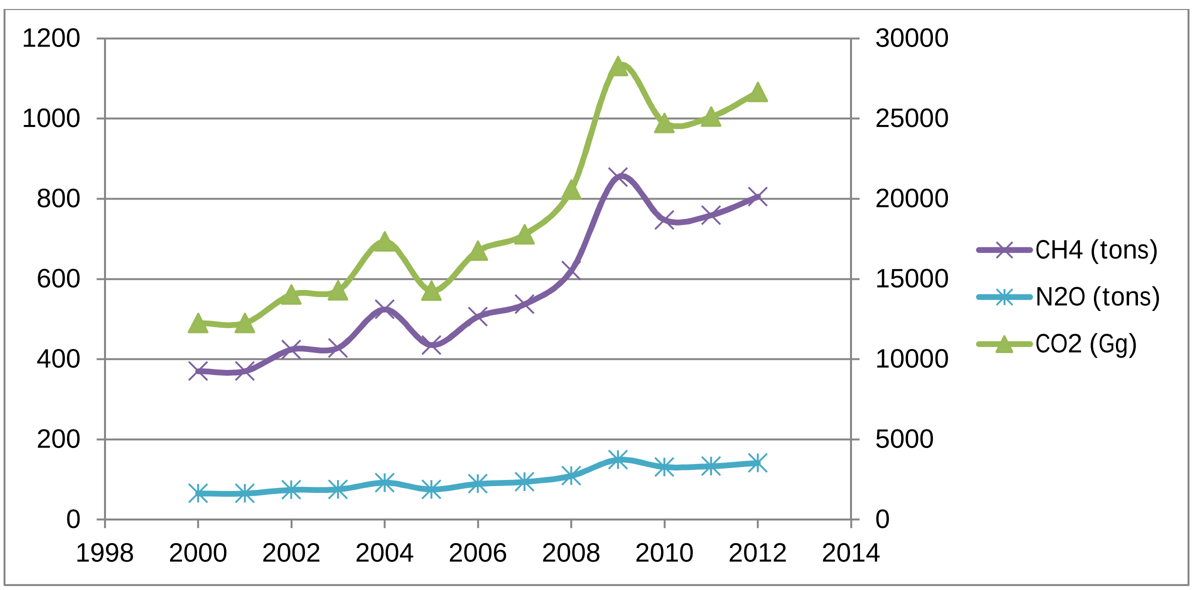


Figure 14 Scenario 9- Greenhouse gas emissions for CO_2, CH_4 and N_20 (Jubail)

Scenario10 – 70% Natural Gas and 30% Fuel Oil.

The estimated greenhouse gas (GHG) emissions for CO_2, CH_4 and N_2O and fuel consumption are illustrated in **Table 11** and **Figure 15** for the years from 2000 to 2012. It was found that the highest CO_2, CH_4 and N_2O emissions from the actual fuel consumption data were 26,502 Gg (2009), 683 tons (2009) and 107 tons (2009) respectively. The lowest CO_2, CH_4 and N_2O emissions were obtained as 11485 Gg (2000-2001), 296 tons (2000-2001), 46 tons (2000-2001), respectively. The trend analysis shows that there is a 11 % more emission of CO_2 when the highest values of actual natural usage were compared with this scenario; hence this blend is a reasonably acceptable within a 20% window of acceptance.

Table 11 Scenario 10 - 70% Natural gas and 30% Fuel Oil.

YEAR	70% NG	30% FUEL OIL	CO_2 (Gg)	CH_4 (tons)	N_2O (tons)
2000	2990061.9	1381573.5	11485	296	46
2001	2990061.9	1381567.6	11485	296	46
2002	3423146.3	1581683	13148	339	53
2003	3577395.5	1578309	13511	345	54
2004	4229988.4	1954488.4	16247	419	66
2005	3796904	1581050	14050	355	55
2006	4087604.5	1888698.9	15700	405	63
2007	4336776.3	2003830.6	16658	430	67
2008	5019032.5	2319070.2	19278	497	77
2009	6899686.5	3188036.3	26502	683	107
2010	6033517.8	2787818.9	23175	598	93
2011	6128440.4	2831678.3	23539	607	98
2012	6502198.1	3004375	24975	644	101

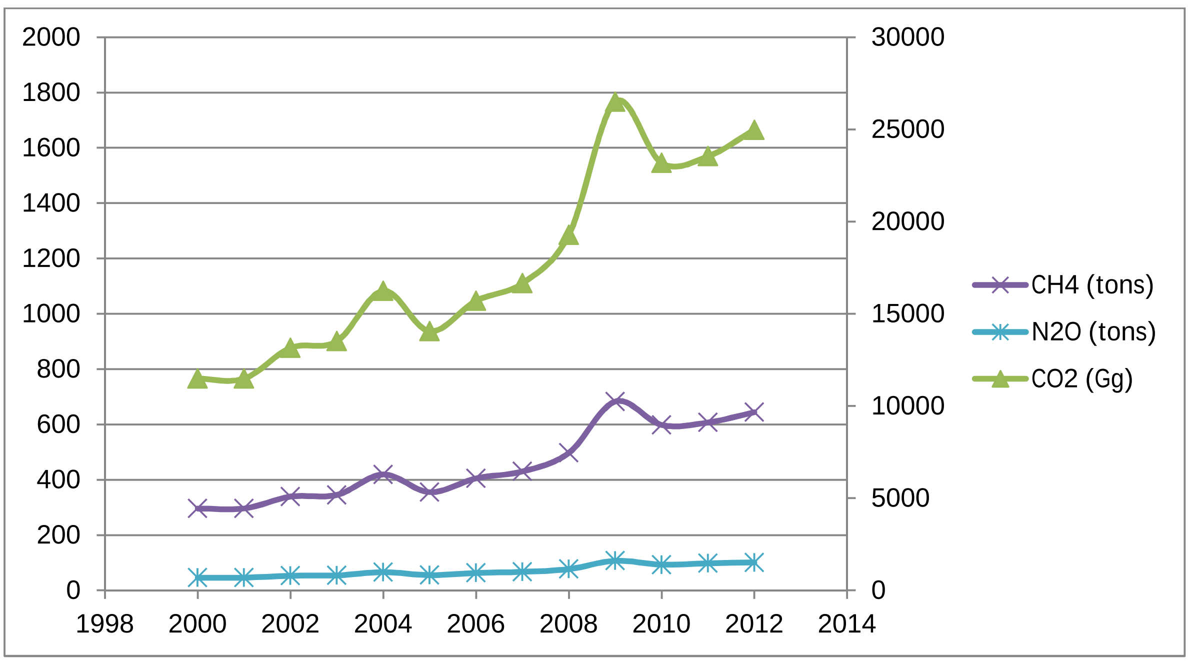


Figure 15 Scenario 10- Greenhouse gas emissions for CO_2, CH_4 and N_20 (Jubail)

EMISSION SCENARIOS FOR NON-GREENHOUSE GASES (NOX, CO, NMVOC, SO2) FOR PURE FUELS (JUBAIL)

Scenario 1 – 100% Natural Gas use (Normal Case)

The primary and most important concern in any greenhouse gas related studies are the directly emitted greenhouses gases namely CO_2, CH_4, N_2O. However, due to health, environmental and socio-economic implications associated to non-greenhouse gases (NO_X, CO, NMVOC and SO_2), their total emission is also considered. The estimated non-greenhouse gas (non-GHG) emissions for as NO_X, CO, NMVOC and SO_2 and fuel consumption are illustrated in **Table 12** and **Figure 16** for the years from 2000 to 2012. It was found that the highest NO_X, CO, NMVOC and SO_2 emissions from the actual fuel consumption data were 64,064 tons (2009), 8,542 tons (2009), 2135 tons (2009) and zero respectively. The lowest NO_X, CO, NMVOC and SO_2 emissions were obtained as 27763tons (2000-2001), 3702 tons (2000-2001), 925 tons (2000-2001) and Zero, respectively. The consistent zero levels of SO_2 recorded is due to the absence of sulphur in Natural gas used in the industrial processes.

Table 12 Scenario 1 - 100% Natural gas.

Year	Fuel (tons)	NOx (Tons)	CO (Tons)	NMVOC (Tons)
2000	4271517	27763	3702	925
2001	4271517	27763	3702	925
2002	4890209	31784	4238	1059
2003	5110565	33216	4429	1107
2004	6042841	39275	5237	1309
2005	5424149	35254	4701	1175
2006	5839435	37953	5060	1265
2007	6195395	40267	5369	1342
2008	7170046	46602	6214	1553
2009	9856695	64064	8542	2135
2010	8619311	56021	7469	1867
2011	8754915	56903	7587	1897
2012	9288854	60373	8050	2012

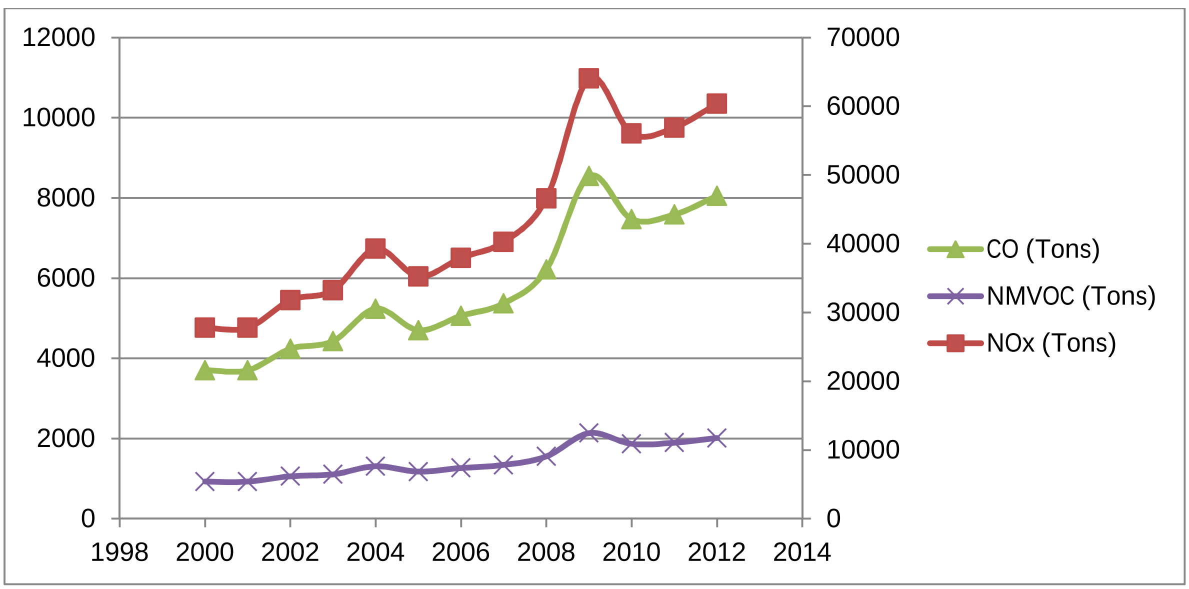


Figure 16 Scenario 1 - Non-Greenhouse emissions for NOx , CO , NMVOC and SO_2 (Jubail)

Scenario 2 – 100% Crude Oil use (Worst Case)

The estimated non-greenhouse gas (non-GHG) emissions for as NO_X, CO, NMVOC and SO_2 and fuel consumption are illustrated in **Table 13** and **Figure 17** for the years from 2000 to 2012. It was found that the highest NO_X, CO, NMVOC and SO_2 emissions from the actual fuel consumption data were 85,418 tons (2009), 6,406 tons (2009), zero and 40,1593 tons (2009) respectively. The lowest NO_X, CO, NMVOC and SO_2 emissions were obtained as 37017 tons (2000-2001), 2776 tons (2000-2001), Zero and 1774035 tons (2000-2001) respectively. The consistent zero levels of NMVOC recorded is due to the absence of NMVOC in Crude Oil used in the industrial processes while high level of SO_2 reflects the high levels of sulphur in Arabian Crude. The 100% crude oil used will lead to other pollution problems such as water, soil and human health problem (skin cancer and asthma). This option should be avoided in all usages due the sever impacts that threatening human health and environment.

Table 13 Scenario 2 - Non-Greenhouse emissions under 100% Crude Oil.

Year	Fuel (tons)	NOx (Tons)	CO (Tons)	SO_2 (Tons)
2000	4350842	37017	2776	174035
2001	4350842	37017	2776	174035
2002	4981025	42379	3178	199249
2003	5205472	44288	3322	208221
2004	6155061	52367	3928	246205
2005	5524888	47006	3525	220998
2006	5947877	50655	3795	237917
2007	6310494	53690	4027	252422
2008	7303199	62136	4660	292131
2009	10039741	85418	6406	401593
2010	8779379	74695	5602	351178
2011	8917501	75870	5690	356703
2012	9461356	80497	6037	378458

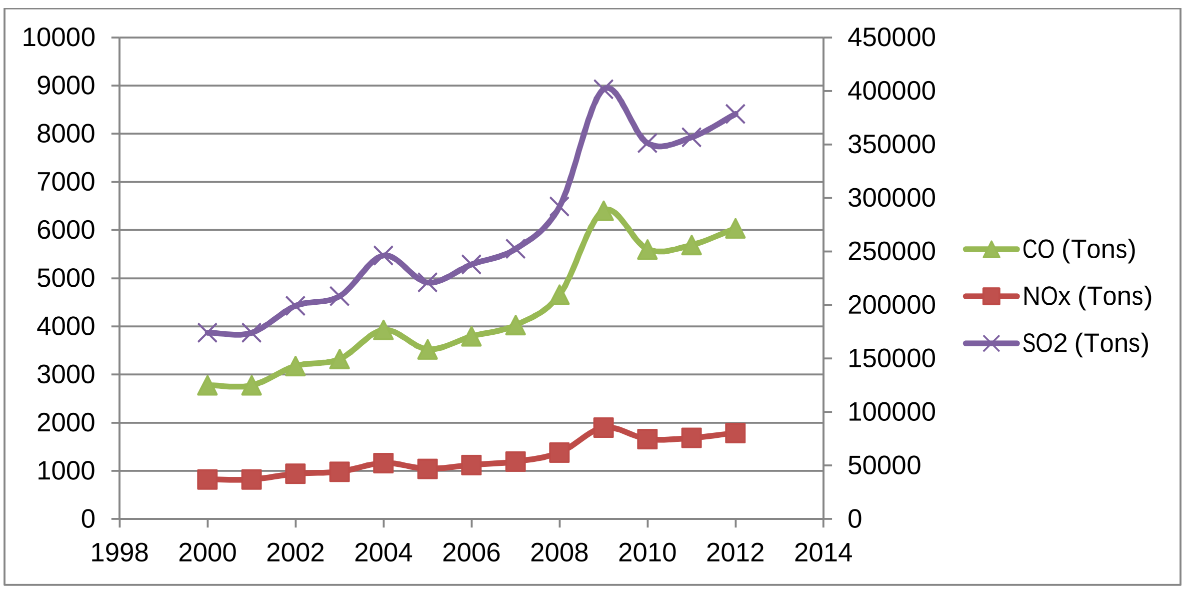


Figure 17 Scenario 2 - Non-Greenhouse emissions for NOx , CO , NMVOC and SO_2 (Jubail)

Scenario 3 – 100% Diesel Fuel use

The estimated non-greenhouse gas (non-GHG) emissions for as NO_X, CO, NMVOC and SO_2 and fuel consumption are illustrated in **Table 14 and Figure 18** for the years from 2000 to 2012. It was found that the highest NO_X, CO, NMVOC and SO_2 emissions from the actual fuel consumption data were 85418 tons (2009), 6404 tons (2009), 2135 tons (2009) and 197145 tons (2009) respectively. The lowest NO_X, CO, NMVOC and SO_2 emissions were obtained as 37017 tons (2000-2001), 2776 tons (2000-2001), 925 tons (2000-2001) and 85435 tons (2000-2001) respectively.

Table 14 Scenario 3 - Non-Greenhouse emissions under 100% Diesel Oil.

Year	Fuel (tons)	NOx (tons)	CO (tons)	NMVOC (tons)	SO_2 (tons)
2000	4271516	37017	2776	925	85435
2001	4271516	37017	2776	925	85435
2002	4890111	42378	3178	1059	97808
2003	5110565	44288	3322	1107	102217
2004	6042836	52367	3928	1309	120864
2005	5424150	47006	3525	1175	108189
2006	5839435	50605	3795	1265	116745
2007	6195396	53684	4027	1342	123916
2008	7170046	62136	4660	1153	143409
2009	9856695	85418	6464	2135	197145
2010	8619312	74695	5602	1867	172396
2011	8754916	75870	5690	1897	175108
2012	9288855	80497	6037	2012	185787

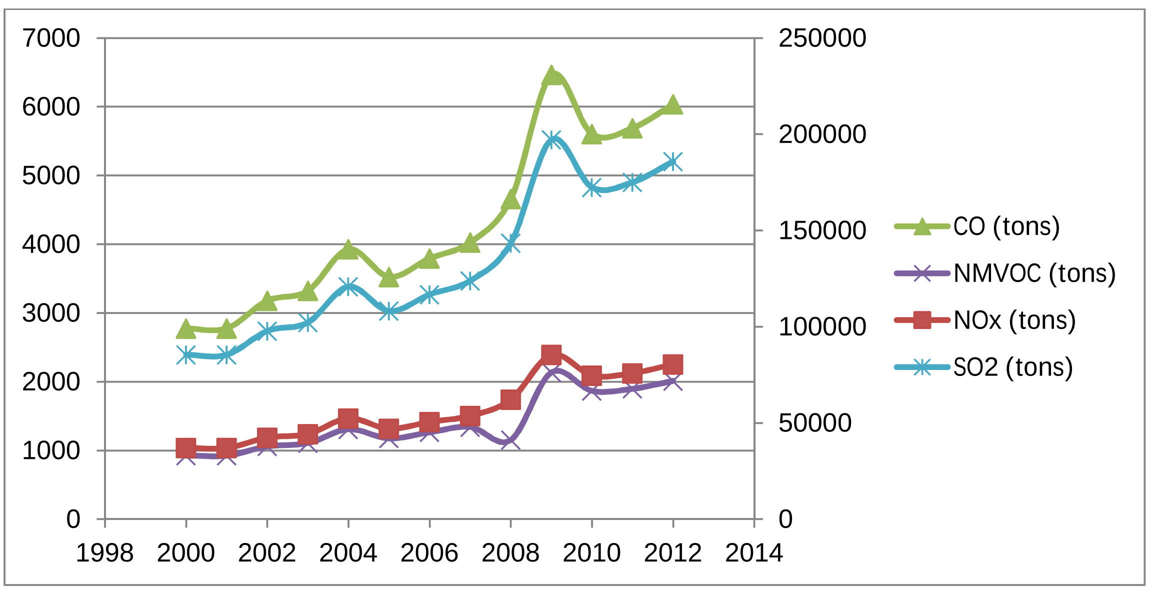


Figure 18 Scenario 3 - Non-Greenhouse emissions for NOx , CO , NMVOC and SO_2 (Jubail)

Scenario 4 – 100% Fuel Oil use

The estimated non-greenhouse gas (non-GHG) emissions for as NO_X, CO, NMVOC and SO_2 are illustrated in **Table 15** and **Figure 19** for the years from 2000 to 2012. It was found that the highest NO_X, CO, NMVOC and SO_2 emissions from the actual fuel consumption data were 85418 tons (2009), 6406 tons (2009), 2135 tons (2009) and 743864 tons (2009) respectively. The lowest NO_X, CO, NMVOC and SO_2 emissions were obtained as 37017 tons (2000-2001), 2776 tons (2000-2001), 925 tons (2000-2001) and 322362 tons (2000-2001) respectively. Diesel and Fuel oil have almost the same emissions except for SO_2 due to their similar calorific value.

Table 15 Scenario 4 - Greenhouse emissions under 100% Fuel Oil.

Year	Fuel (tons)	NOx (Tons)	CO (tons)	NMVOC (Tons)	SO2 (Tons)
2000	4605245.1	37017	2776	925	322366.2
2001	4605245.1	37017	2776	925	322366.2
2002	5272276.7	42379	3178	1059	369043.7
2003	5261030.1	42288	3172	1057	368866.4
2004	6514961.4	52367	3928	1309	456040.3
2005	5270166.7	42362	3177	1059	368406
2006	6295663.1	50605	3795	1265	440689.6
2007	6679435.2	53689	4027	1342	467553.3
2008	7730233.9	62136	4660	1553	541108
2009	10626788	85418	6406	2135	743863.7
2010	9292729.5	74695	5602	1867	650481.1
2011	9438927.6	75870	5690	1897	660714.8
2012	10014583	80497	6037	2012	701010

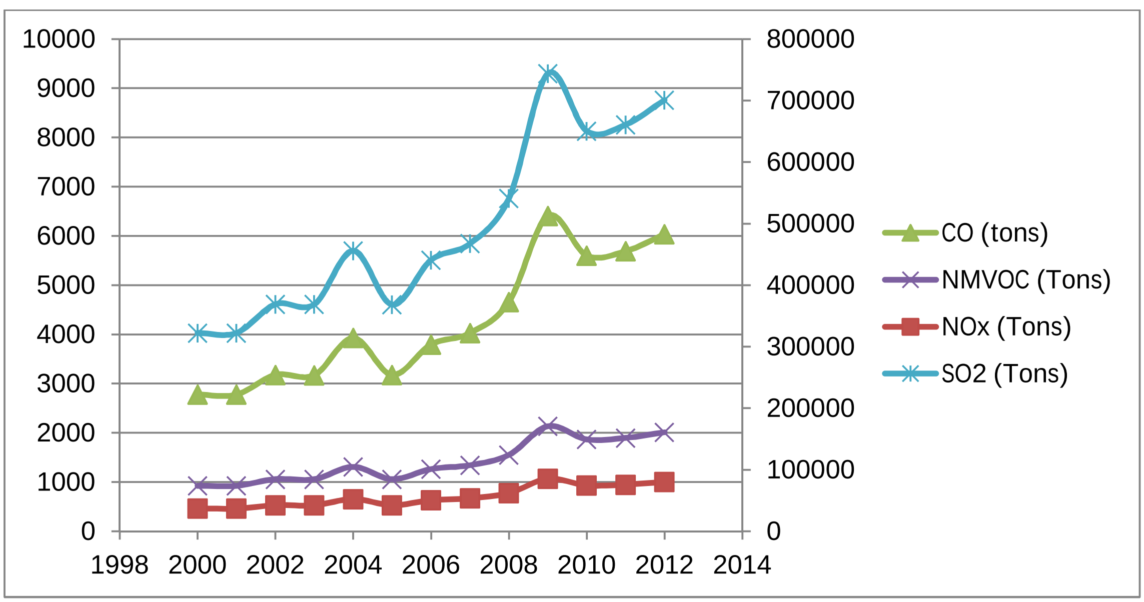


Figure 19 Scenario 4 - Non-Greenhouse emissions for NOx , CO , NMVOC and SO_2 (Jubail)

EMISSION SCENARIOS WITH BLENDED FUELS (JUBAIL)

Scenario 5 – 50% Natural Gas and 50% Crude Oil Use.

The estimated non-greenhouse gas (non-GHG) emissions for as NO_X, CO, NMVOC and SO_2 are illustrated in **Table 16** and **Figure 20** for the years from 2000 to 2012. It was found that the highest NO_X, CO, NMVOC and SO_2 emissions from the actual fuel consumption data were 74741 tons (2009), 7474 tons (2009), 1068 tons (2009) and 200797 tons (2009) respectively. The lowest NO_X, CO, NMVOC and SO_2 emissions were obtained as 32390 tons (2000-2001), 3239 tons (2000-2001), 463 tons (2000-2001) and 87018 tons (2000-2001) respectively.

Table 16 Scenario 5 – Non-Greenhouse emissions under 50% Natural gas and 50% Crude Oil.

YEAR	50% NG	50% Crude oil	NOx (Tons)	CO (Tons)	NMVOC (Tons)	SO2 (Tons)
2000	2135758.5	2175421	32390	3239	463	87018
2001	2135758.5	2175421	32390	3239	463	87018
2002	2445104.5	2490512.5	37081	3708	530	99621
2003	2555282.5	2602736	38752	3825	554	104110
2004	3021420.3	3077530.5	45821	4582	655	123103
2005	2712074.3	2762444	41130	4113	588	110499
2006	2919717.5	2973938.5	44279	4428	633	118959
2007	3097697.4	3155247	46978	4698	671	126211
2008	3585023.2	3651599.5	54369	5437	777	146065
2009	4928347.5	5019870.5	74741	7474	1068	200797
2010	4309655.6	4389689.5	65358	6536	934	175589
2011	4377457.4	4458750.5	66386	6639	948	178352
2012	4644427.2	4730678	70435	7044	1006	189229

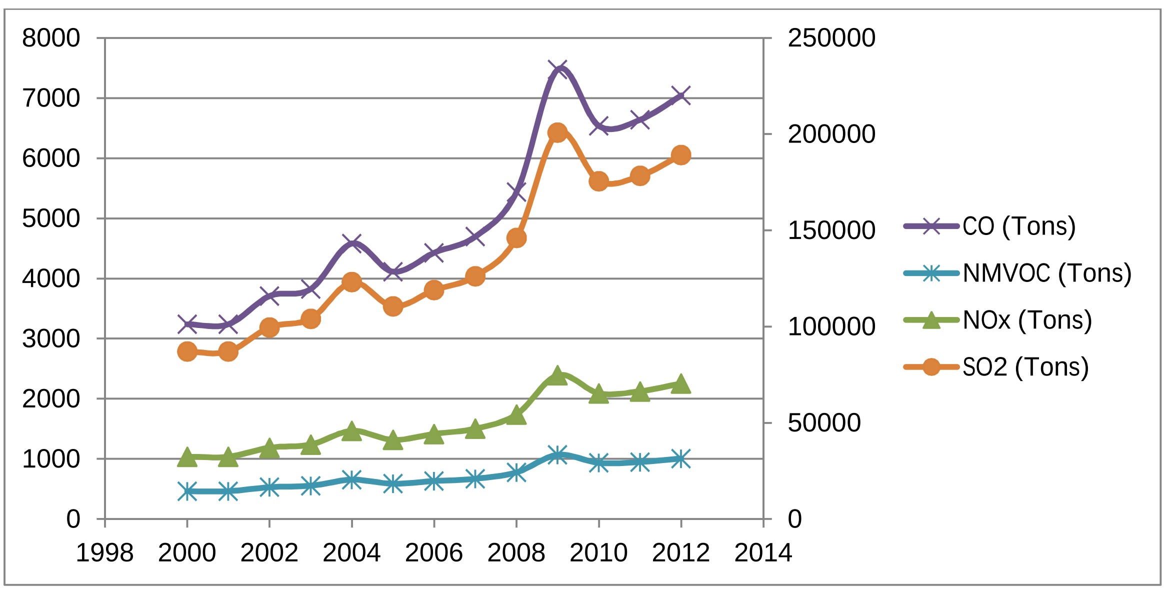


Figure 20 Scenario 5 - Non-Greenhouse emissions for NOx , CO , NMVOC and SO_2 (Jubail)

Scenario 6 – 70% Natural Gas and 30% Crude Oil Use.

The estimated non-greenhouse gas (non-GHG) emissions for as NO_X, CO, NMVOC and SO_2 are illustrated in **Table 17** and **Figure 21** for the years from 2000 to 2012. It was found that the highest NO_X, CO, NMVOC and SO_2 emissions from the actual fuel consumption data were 70470 tons (2009), 7901 tons (2009), 1495 tons (2009) and 120478 tons (2009) respectively. The lowest NO_X, CO, NMVOC and SO_2 emissions were obtained as 30539 tons (2000-2001), 3424 tons (2000-2001), 648 tons (2000-2001) and 52211 tons (2000-2001) respectively.

Table 17 Scenario 6 – Non- Greenhouse emissions under 70% Natural gas and 30% Crude Oil.

YEAR	70% NG	30% Crude oil	NOx (Tons)	CO (Tons)	NMVOC (Tons)	SO2 (Tons)
2000	2990061.9	1305252.6	30539	3424	648	52211
2001	2990061.9	1305252.6	30539	3424	648	52211
2002	3423146.3	1494307.5	34962	3920	742	59773
2003	3577395.5	1561641.6	36538	4097	775	62466
2004	4229988.4	1846518.3	43203	4844	916	73861
2005	3796904	1657466.4	38780	4348	823	66299
2006	4087604.5	1784363.1	41749	4681	886	71375
2007	4336776.3	1893148.2	44294	4966	940	75727
2008	5019032.5	2190959.7	51262	5748	1087	87639
2009	6899686.5	3011922.3	70470	7901	1495	120478
2010	6033517.8	2633813.7	61623	6909	1307	105354
2011	6128440.4	2675250.3	62593	7018	1328	107011
2012	6502198.1	2838406.8	64410	7446	1409	113537

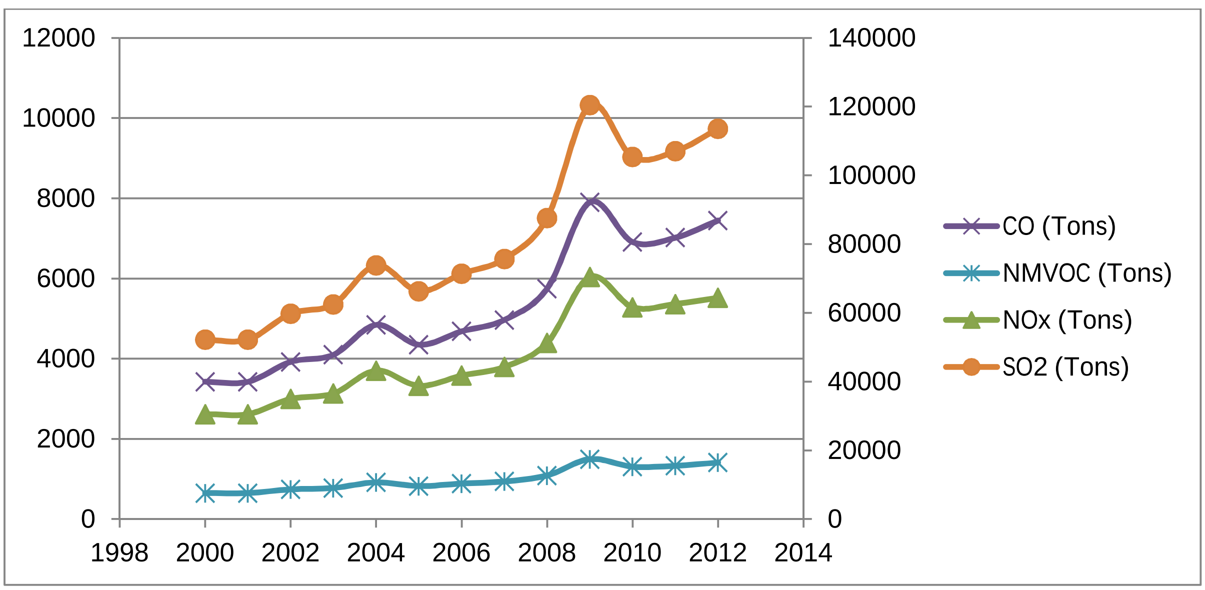


Figure 21 Scenario 6 - Non-Greenhouse emissions for NOx , CO , NMVOC and SO_2 (Jubail)

Scenario 7 – 50% Natural Gas and 50% Diesel Use.

The estimated non-greenhouse gas (non-GHG) emissions for as NO_X, CO, NMVOC and SO_2 are illustrated in **Table 18** and **Figure 22** for the years from 2000 to 2012. It was found that the highest NO_X, CO, NMVOC and SO_2 emissions from the actual fuel consumption data were 74741 tons (2009), 7474 tons (2009), 2135 tons (2009) and 98573 tons (2009) respectively. The lowest NO_X, CO, NMVOC and SO_2 emissions were obtained as 32390 tons (2000-2001), 3239 tons (2000-2001), 295 tons (2000-2001) and 42718 tons (2000-2001) respectively.

Table 18 Scenario 7- Non-Greenhouse emissions under 50% Natural gas and 50% Diesel Oil

YEAR	50% NG	50% Diesel	NOx (tons)	CO (tons)	NMVOC (tons)	SO2 (tons)
2000	2135758.5	2135758	32390	3239	925	42718
2001	2135758.5	2135758	32390	3239	925	42718
2002	2445104.5	2445055.5	37081	3708	1059	48904
2003	2555282.5	2555282.5	38752	3875	1107	51109
2004	3021420.3	3021418	45821	4582	1309	50432
2005	2712074.3	2712075	41130	4113	1175	54245
2006	2919717.5	2919717.5	44279	4428	1265	58398
2007	3097697.4	3097698	46978	4698	1342	61957
2008	3585023.2	3585023	54369	5437	1553	71705
2009	4928347.5	4928347.5	74741	7474	2135	98573
2010	4309655.6	4309656	63558	6536	1867	86198
2011	4377457.4	4377458	66386	6639	1897	87554
2012	4644427.2	4644427.5	70535	7044	2012	92894

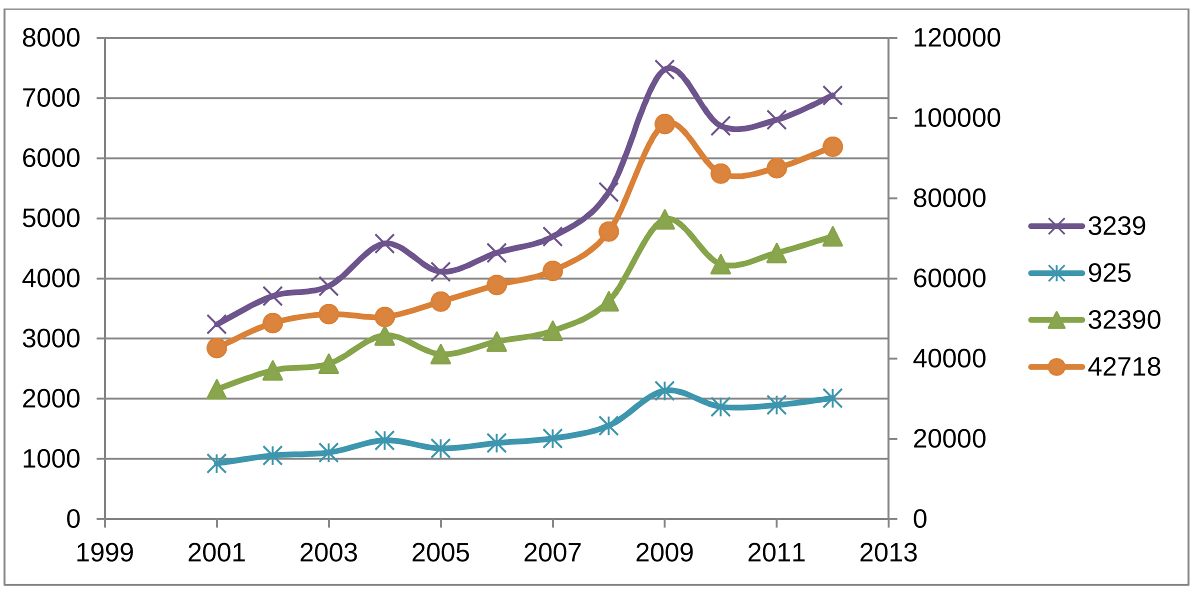


Figure 22 Scenario 7 - Non-Greenhouse emissions for NOx , CO , NMVOC and SO_2 (Jubail)

Scenario 8 – 70% Natural Gas and 30% Diesel Use.

The estimated non-greenhouse gas (non-GHG) emissions for as NO_X, CO, NMVOC and SO_2 are illustrated in **Table 19** and **Figure 23** for the years from 2000 to 2012. It was found that the highest NO_X, CO, NMVOC and SO_2 emissions from the actual fuel consumption data were 70470 tons (2009), 7901 tons (2009), 2135 tons (2009) and 59144 tons (2009) respectively. The lowest NO_X, CO, NMVOC and SO_2 emissions were obtained as 30539 tons (2000-2001), 3424 tons (2000-2001), 925 tons (2000-2001) and 25631 tons (2000-2001) respectively.

Table 19 Scenario 8 – Non-Greenhouse emissions under 70% Natural gas and 30% Diesel Oil .

YEAR	70% NG	30% Diesel	NOx (Tons)	CO (Tons)	NMVOC (Tons)	SO2 (Tons)
2000	2990061.9	1281454.8	30539	3424	925	25631
2001	2990061.9	1281454.8	30539	3424	925	25631
2002	3423146.3	1467033.3	34962	3920	1059	29342
2003	3577395.5	1533169.5	36538	4097	1107	30665
2004	4229988.4	1812850.8	43203	4844	1309	35259
2005	3796904	1627245	38700	4348	1175	32547
2006	4087604.5	1751830.5	41749	4681	1265	35039
2007	4336776.3	1858618.8	44294	4966	1342	34175
2008	5019032.5	2151013.8	51262	5748	1563	43023
2009	6899686.5	2957008.5	70470	7901	2135	59144
2010	6033517.8	2585793.6	61623	6909	1869	51719
2011	6128440.4	2626474.8	62593	7018	1887	52533
2012	6502198.1	2786656.5	66410	7446	2012	55737

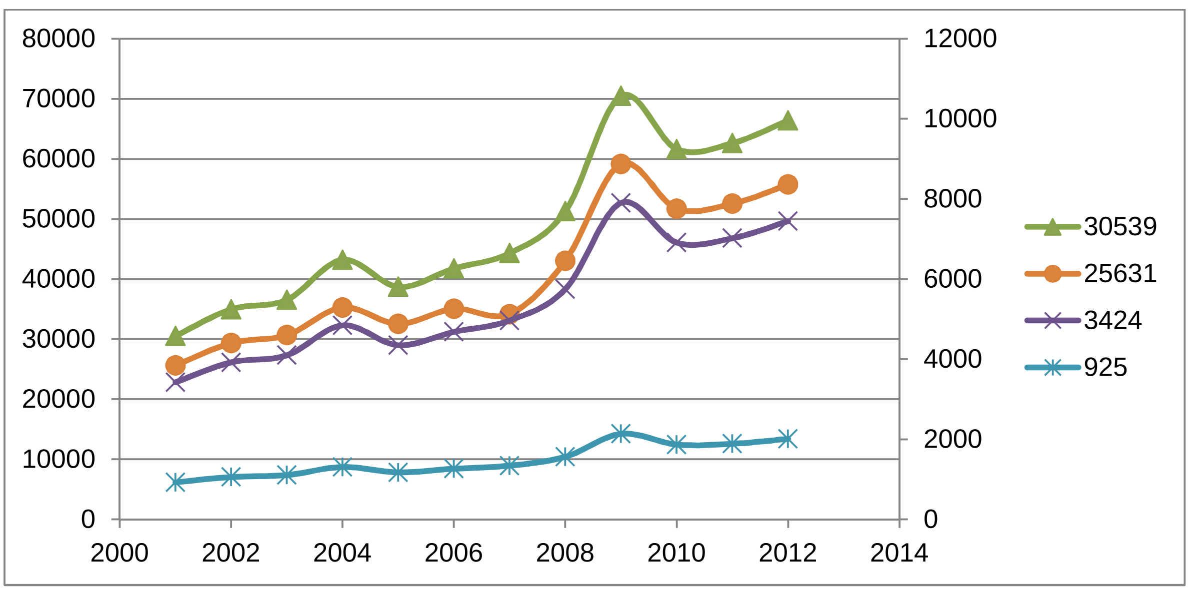


Figure 23 Scenario 8 - Non-Greenhouse emissions for NOx , CO , NMVOC and SO_2 (Jubail)

Scenario 9 – 50% Natural Gas and 50% Fuel Oil Use.

The estimated non-greenhouse gas (non-GHG) emissions for as NO_X, CO, NMVOC and SO_2 are illustrated in **Table 20** and **Figure 24** for the years from 2000 to 2012. It was found that the highest NO_X, CO, NMVOC and SO_2 emissions from the actual fuel consumption data were 74741 tons (2009), 7474 tons (2009), 2135 tons (2009) and 371932 tons (2009) respectively. The lowest NO_X, CO, NMVOC and SO_2 emissions were obtained as 32390 tons (2000-2001), 3239 tons (2000-2001), 925 tons (2000-2001) and 161181 tons (2000-2001) respectively.

Table 20 Scenario 9 – Non-Greenhouse emissions under 50% Natural gas and 50% Fuel Oil.

YEAR	50% NG	50% FUEL OIL	NOx (tons)	CO (tons)	NMVOC (tons)	SO2 (tons)
2000	2135758.5	2302622.5	32390	3239	925	161181
2001	2135758.5	2302612.6	32390	3239	925	161181
2002	2445104.5	2636138.3	37081	3708	1059	184527
2003	2555282.5	2630515.1	37752	3800	1082	184133
2004	3021420.3	3257480.7	45821	4582	1309	228020
2005	2712074.3	2635083.4	38808	3939	1117	184453
2006	2919717.5	3147831.6	44279	4428	1265	220345
2007	3097697.4	3339717.6	46978	4698	1342	233777
2008	3585023.2	3865116.9	54369	5437	1553	270554
2009	4928347.5	5313393.9	74741	7474	2135	371932
2010	4309655.6	4646364.8	65358	6536	1867	325241
2011	4377457.4	4719463.8	66386	6639	1897	330357
2012	4644427.2	5007291.6	70435	7044	2012	350505

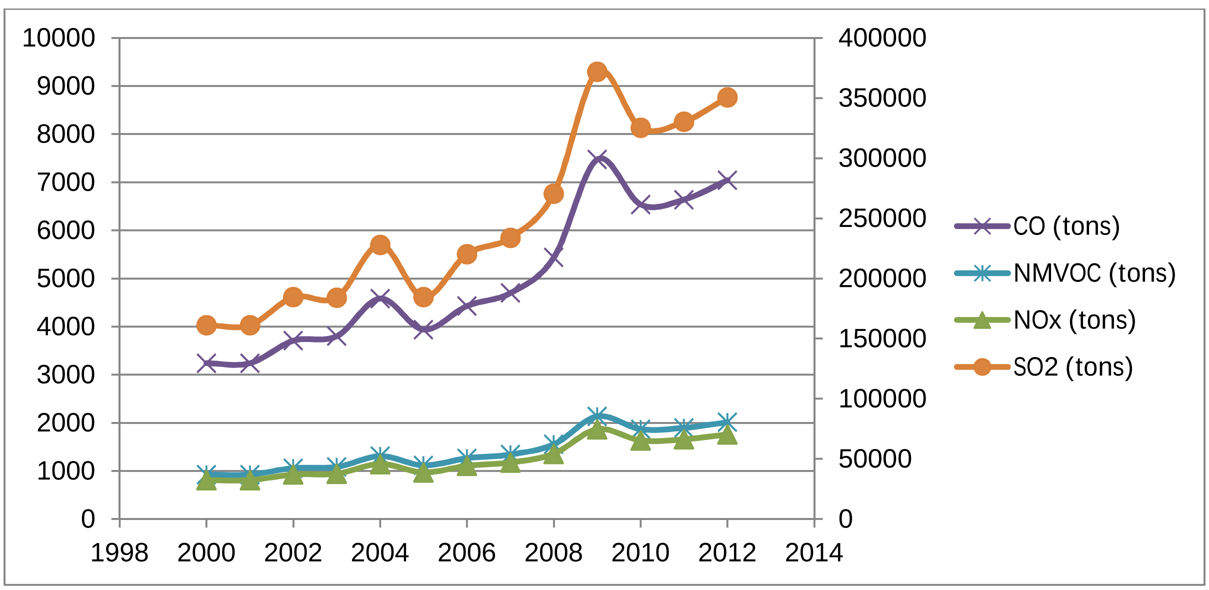


Figure 24 Scenario 9 - Non-Greenhouse emissions for NOx , CO , NMVOC and SO_2 (Jubail)

Scenario 10 – 70% Natural Gas and 30% Fuel Oil Use.

The estimated non-greenhouse gas (non-GHG) emissions for as NO_X, CO, NMVOC and SO_2 are illustrated in **Table 21** and **Figure 25** for the years from 2000 to 2012. It was found that the highest NO_X, CO, NMVOC and SO_2 emissions from the actual fuel consumption data were 70470 tons (2009), 7901 tons (2009), 2135 tons (2009) and 223159 tons (2009) respectively. The lowest NO_X, CO, NMVOC and SO_2 emissions were obtained as 30539 tons (2000-2001), 3424 tons (2000-2001), 925 tons (2000-2001) and 96709 tons (2000-2001) respectively.

Table 21 Scenario 10 – Non Greenhouse emissions under 70% Natural gas and 30% Fuel Oil.

YEAR	70% NG	30% FUEL OIL	NOx (Tons)	CO (Tons)	NMVOC (Tons)	SO2 (Tons)
2000	2990061.9	1381573.5	30539	3424	925	96708.7
2001	2990061.9	1381567.6	30539	3424	925	96708.7
2002	3423146.3	1581683	34962	3920	1059	110716.1
2003	3577395.5	1578309	35938	4052	1092	110479.9
2004	4229988.4	1954488.4	43203	4844	1309	136812.1
2005	3796904	1581050	37386	4244	1140	110671.8
2006	4087604.5	1888698.9	41749	4681	1265	132206.9
2007	4336776.3	2003830.6	44294	4966	1342	140266
2008	5019032.5	2319070.2	51262	5748	1553	162332.4
2009	6899686.5	3188036.3	70470	7901	2135	223159.1
2010	6033517.8	2787818.9	61623	6909	1867	195144.3
2011	6128440.4	2831678.3	62593	7018	1897	198214.4
2012	6502198.1	3004375	66410	7446	2012	210303

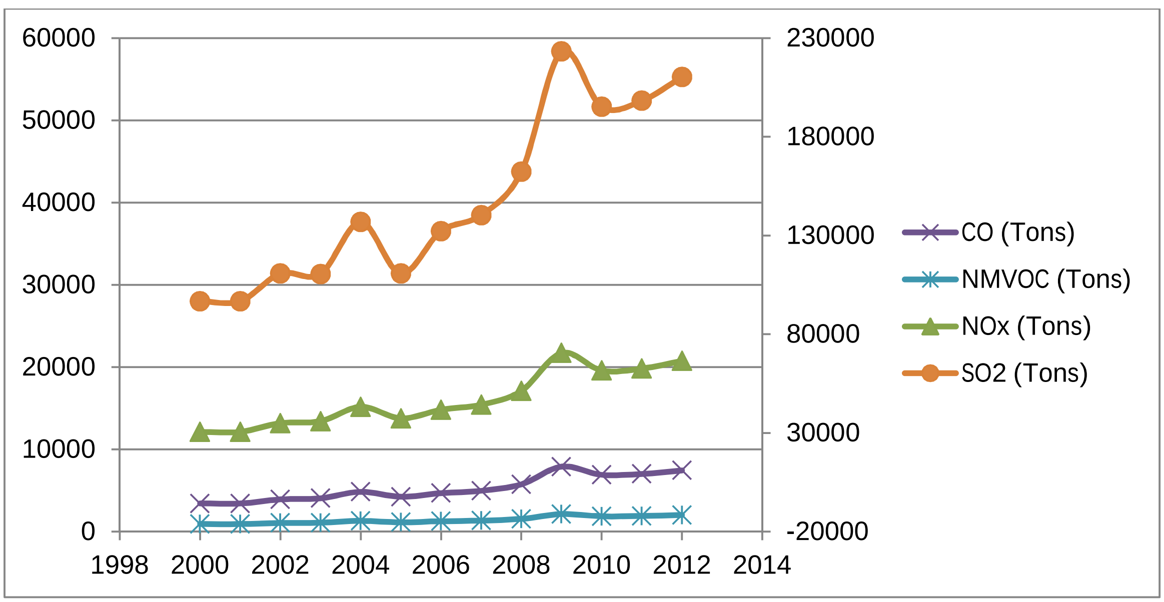


Figure 25 Scenario 10 - Non-Greenhouse emissions for NOx , CO , NMVOC and SO_2 (Jubail)

EMISSION SCENARIOS FOR YANBU

Scenario 1 – 100% Natural Gas use (Normal Case)

The estimated greenhouse gas (GHG) emissions for CO_2, CH_4 and N_2O is presented in **Table 22** and **Figure 26** for the years from 2008 to 2012. It was found that the highest CO_2, CH_4 and N_2O emissions from the actual fuel consumption data were 46 Gg (2009), 0.8 tons (2009) and 0.1 tons (2009) respectively. The trend analysis shows that there is a constants increment in the emission rate from 2008-2014. This scenario forms the basis for comparison for all other fuel consumption scenarios.

Table 22 Scenario 1 – 100% Natural Gas use (Normal Case)

YEAR	CO_2 (Gg)	CH_4 (tons)	N_2O (tons)
2008	24	0.4	0
2009	46	0.8	0.1
2010	45	0.8	0.1
2011	59	1.1	0.1
2012	59	1.1	0.1

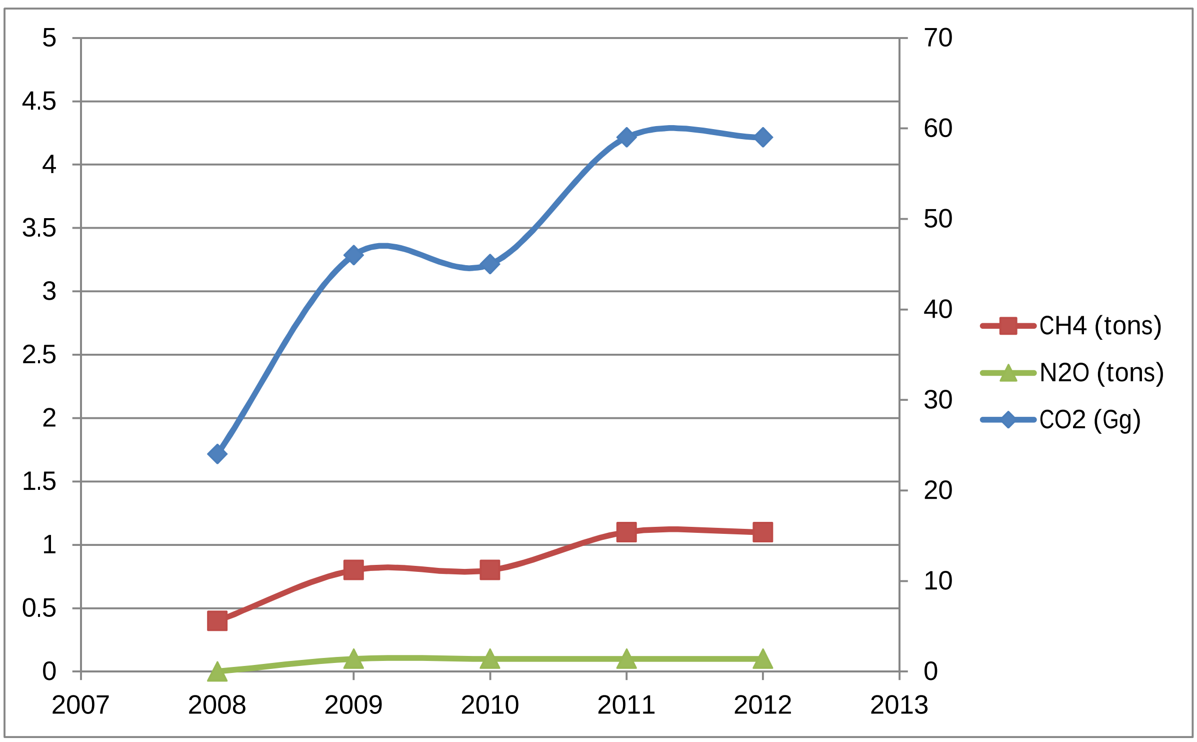


Figure 26 Scenario 1 - Greenhouse gas emissions for CO_2, CH_4 and N_20 (Yanbu)

Scenario 2 – 100% Crude Oil use

The estimated greenhouse gas (GHG) emissions for CO_2, CH_4 and N_2O in **Table 23** and **Figure 27** for the years from 2008 to 2012. It was found that the highest CO_2, CH_4 and N_2O emissions from the actual fuel consumption data were 60 Gg (2009), 2.5 tons (2009) and 0.8tons (2010) respectively. The trend analysis shows that as compared to natural gas emission values, crude oil produce higher emissions with about hence might not be a good substitute fuel. Also, there is a remarkable level of SO_2 emissions from the usage of crude oil that will generate similar energy to natural gas. SO_2 emission has been implicated in several health related conditions. From the analysis above, it is evident that the government (Saudi Arabia) needs to work toward reducing the reliance on the usage of this option due to the severity of it impacts on human health and environment.

Table 23 Scenario 2 – 100% Crude Oil use

YEAR	CO_2 (Gg)	CH_4 (tons)	N_2O (tons)
2008	31	1.3	0.3
2009	60	2.5	0.5
2010	59	2.4	0.8
2011	77	3.2	0.6
2012	77	3.2	0.6

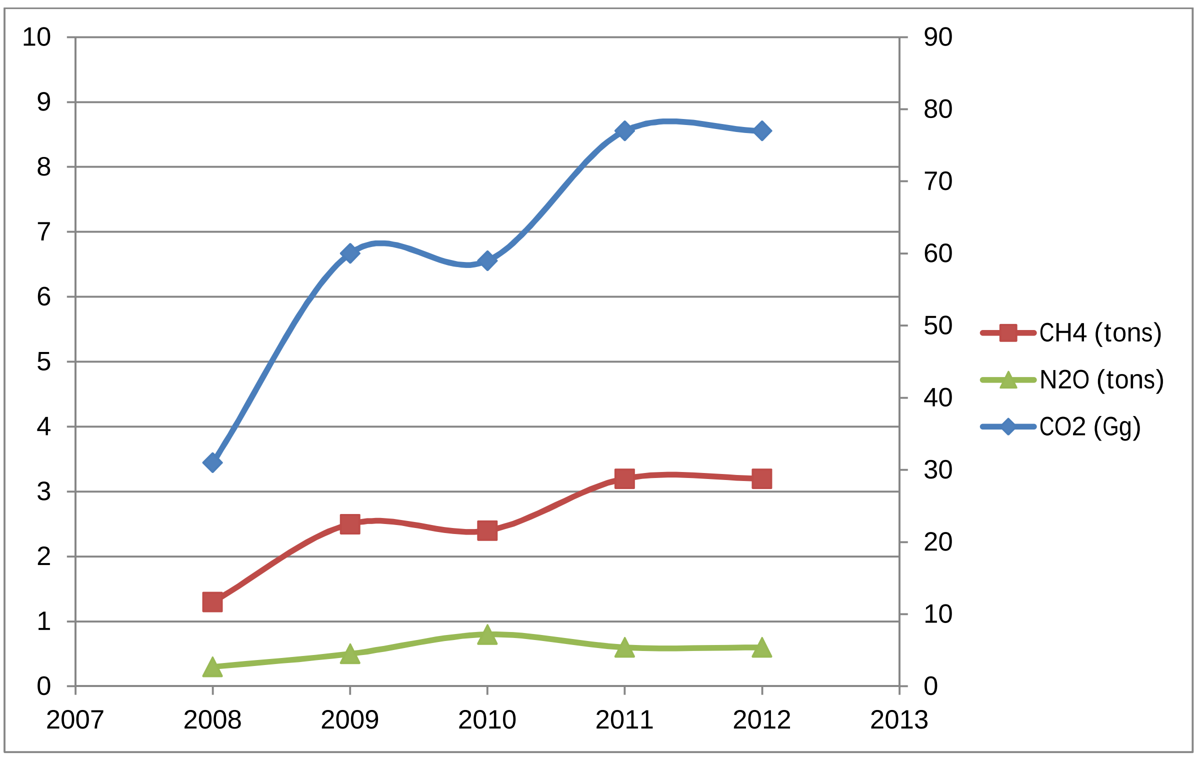


Figure 27 Scenario 2 - Greenhouse gas emissions for CO_2, CH_4 and N_20 (Yanbu)

Scenario 3 – 100% Diesel Fuel use

The estimated greenhouse gas (GHG) emissions for CO_2, CH_4 and N_2O in **Table 24** and **Figure 28** for the years from 2008 to 2012. It was found that the highest CO_2, CH_4 and N_2O emissions from the actual fuel consumption data were 61 Gg (2009), 2.5 tons (2009) and 0.5 tons (2009) respectively.. The trend analysis shows that Diesel produces a 30% increment in CO_2 emissions over the use of natural gas when the highest actual consumption value considered and has a lower SO_2 emission as compared with the usage of crude oil (51% decrease). Hence, the diesel scenario is a prospective candidate for the fuel substitute.

Table 24 Scenario 3 – 100% Diesel Fuel use

YEAR	CO_2 (Gg)	CH_4 (tons)	N_2O (tons)
2008	31	1.3	0.3
2009	61	2.5	0.5
2010	60	2.4	0.5
2011	78	3.2	0.6
2012	78	3.2	0.6

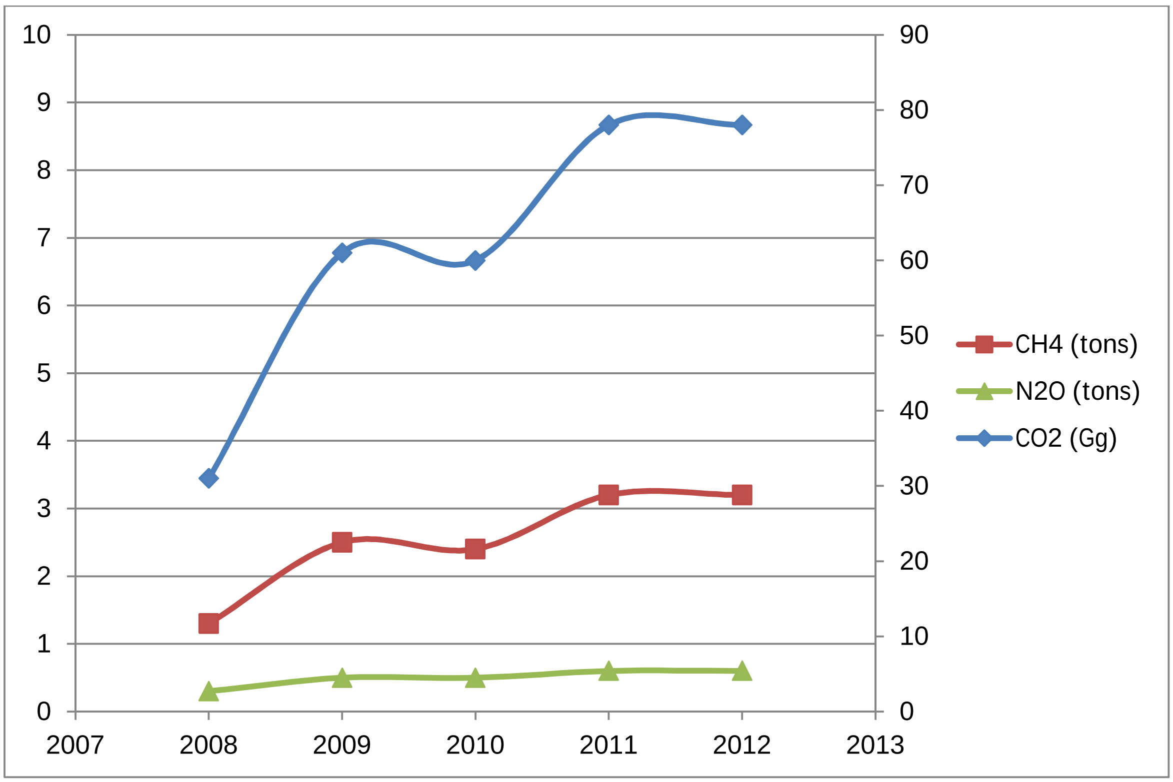


Figure 28 Scenario 3 - Greenhouse gas emissions for CO_2, CH_4 and N_20 (Yanbu)

Scenario 4 – 100% Fuel Oil use

The estimated greenhouse gas (GHG) emissions for CO_2, CH_4 and N_2O in **Table 25** and **Figure 29** for the years from 2008 to 2012. It was found that the highest CO_2, CH_4 and N_2O emissions from the actual fuel consumption data were 64 Gg (2009), 2.5 tons (2009) and 0.5 tons (2009-2010) respectively. The trend analysis shows that Fuel oil produces a 37% increment in CO_2 emissions over the use of natural gas when the highest actual consumption value is considered.

Table 25 Scenario 4 – 100% Fuel Oil use

YEAR	CO_2 (Gg)	CH_4 (tons)	N_2O (tons)
2008	32	1.3	0.3
2009	64	2.5	0.5
2010	62	2.4	0.5
2011	81	3.2	0.6
2012	81	3.2	0.6

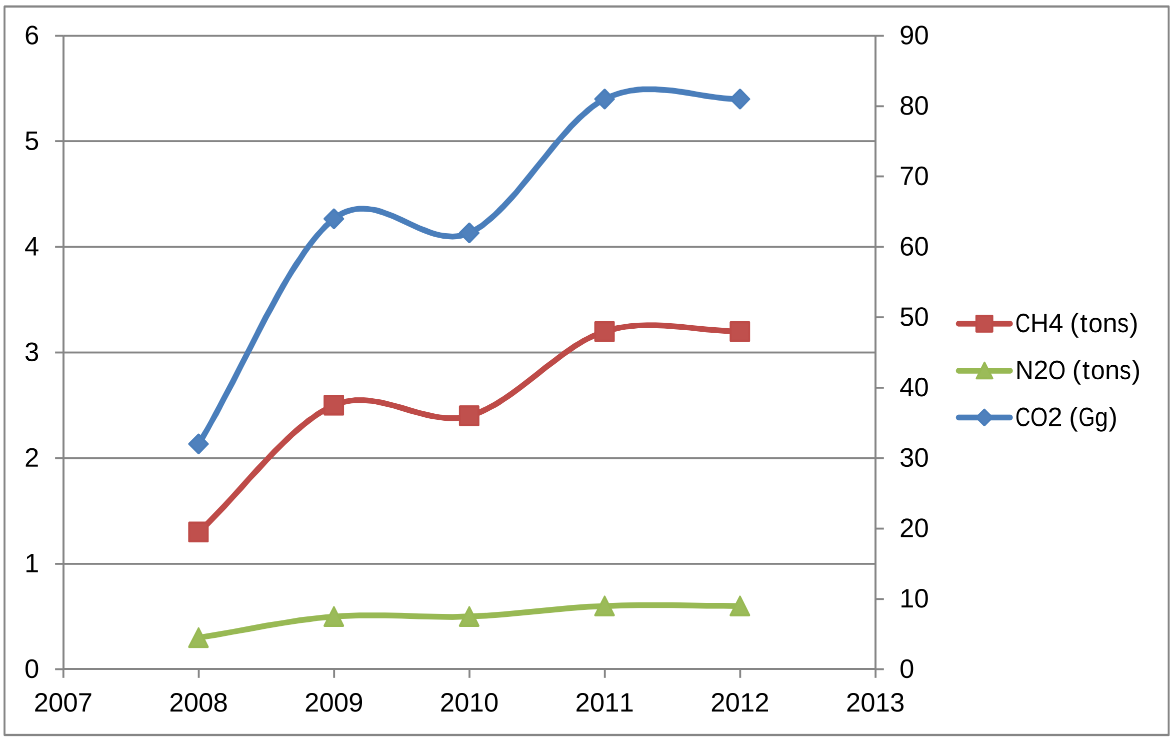


Figure 29 Scenario 4 - Greenhouse gas emissions for CO_2, CH_4 and N_20 (Yanbu)

EMISSION SCENARIOS OF DIRECT GREENHOUSE WITH BLENDED FUELS (YANBU)

Scenario 5 – 50% Natural Gas and 50% Crude Oil Use.

The estimated greenhouse gas (GHG) emissions for CO_2, CH_4 and N_2O in **Table 26** and **Figure 30** for the years from 2008 to 2012. It was found that the highest CO_2, CH_4 and N_2O emissions from the actual fuel consumption data were 53 Gg (2009), 1.7 tons (2009) and 0.3 tons (2009-2010) respectively. The trend analysis shows that there is a 15 % more emission of CO_2 when the highest values of actual natural usage were compared with this scenario; hence this blend is a good reasonably acceptable within a 20% window of acceptance.

Table 26 Scenario 5 – 50% Natural Gas and 50% Crude Oil Use.

YEAR	CO_2 (Gg)	CH_4 (tons)	N_2O (tons)
2008	27	0.8	0.1
2009	53	1.7	0.3
2010	52	1.6	0.3
2011	68	2.1	0.4
2012	68	2.1	0.4

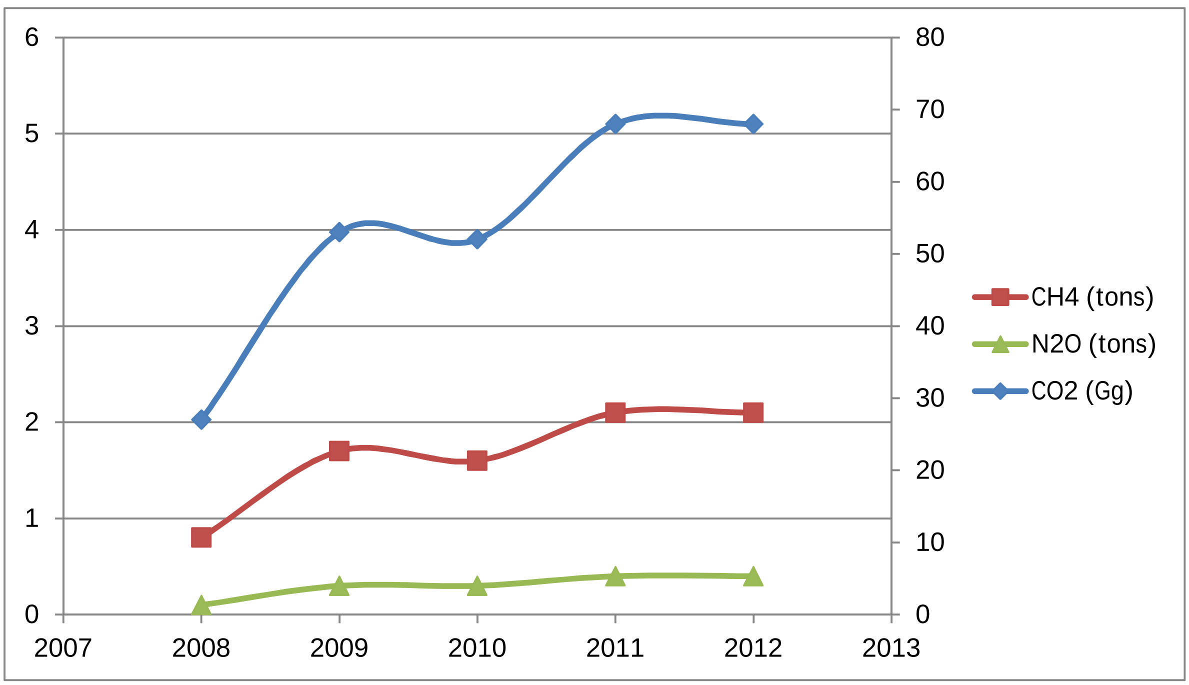


Figure 30 Scenario 5 - Greenhouse gas emissions for CO_2, CH_4 and N_20 (Yanbu)

Scenario 6 – 70% Natural Gas and 30% Crude Oil Use.

The estimated greenhouse gas (GHG) emissions for CO_2, CH_4 and N_2O illustrated in **Table 27** and **Figure 31** for the years from 2008 to 2012. It was found that the highest CO_2, CH_4 and N_2O emissions from the actual fuel consumption data were 5.1 Gg (2009), 1.3 tons (2009-2010) and 0.2 tons (2009) respectively. The trend analysis shows that there is a 9 % more emission of CO_2 when the highest values of actual natural usage were compared with this scenario; hence this blend is a reasonably acceptable within a 20% window of acceptance.

Table 27 Scenario 6 – 70% Natural Gas and 30% Crude Oil Use.

YEAR	CO_2 (Gg)	CH_4 (tons)	N_2O (tons)
2008	26	0.7	0.1
2009	51	1.3	0.2
2010	50	1.3	0.2
2011	64	1.7	0.3
2012	64	1.7	0.3

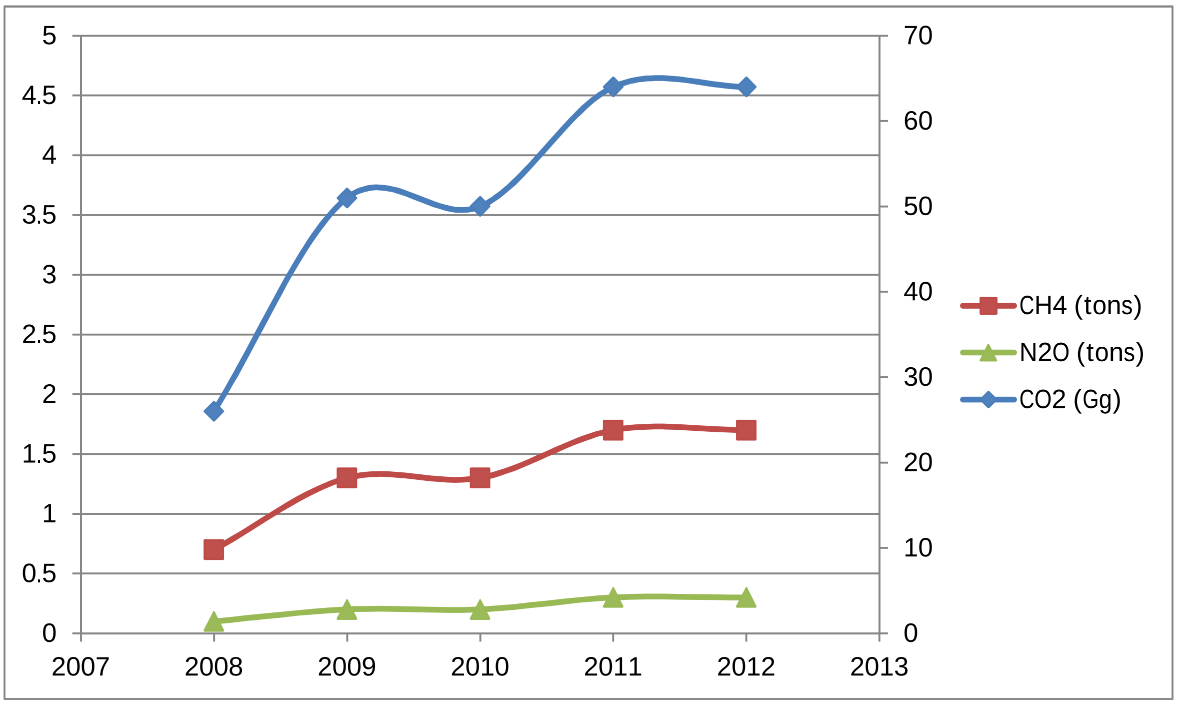


Figure 31 Scenario 6 - Greenhouse gas emissions for CO_2, CH_4 and N_20 (Yanbu)

Scenario 7 – 50% Natural Gas and 50% Diesel Use.

The estimated greenhouse gas (GHG) emissions for CO_2, CH_4 and N_2O in **Table 28** and **Figure 32** for the years from 2008 to 2012. It was found that the highest CO_2, CH_4 and N_2O emissions from the actual fuel consumption data were 54 Gg (2009), 1.7 tons (2009) and 0.3 tons (2009-2010) respectively. The trend analysis shows that there is a 16 % more emission of CO_2 when the highest values of actual natural usage were compared with this scenario; hence this blend is a reasonably acceptable within a 20% window of acceptance.

Table 28 Scenario 7 – 50% Natural Gas and 50% Diesel Use.

YEAR	CO_2 (Gg)	CH_4 (tons)	N_2O (tons)
2008	27	0.3	0.1
2009	54	1.7	0.3
2010	53	1.6	0.3
2011	68	2	0.4
2012	68	2	0.4

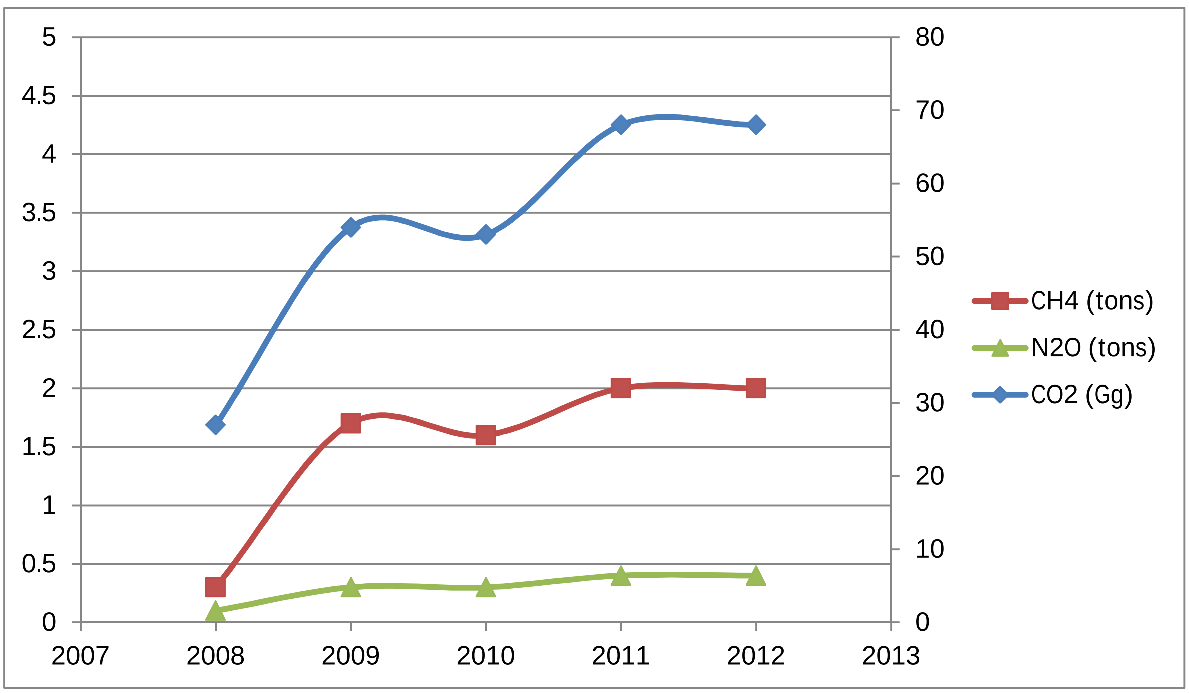


Figure 32 Scenario 7 - Greenhouse gas emissions for CO_2, CH_4 and N_20 (Yanbu)

Scenario 8 – 70% Natural Gas and 30% Diesel Use.

The estimated greenhouse gas (GHG) emissions for CO_2, CH_4 and N_2O illustrated in **Table 29** and **Figure 33** for the years from 2008 to 2012. It was found that the highest CO_2, CH_4 and N_2O emissions from the actual fuel consumption data were 52 Gg (2009), 1.3 tons (2009) and 0.2 tons (2009-2010) respectively. The trend analysis shows that there is a 9 % more emission of CO_2 when the highest values of actual natural usage were compared with this scenario; hence this blend is a reasonably acceptable within a 20% window of acceptance.

Table 29 Scenario 8 – 70% Natural Gas and 30% Diesel Use.

YEAR	CO_2 (Gg)	CH_4 (tons)	N_2O (tons)
2008	26	0.7	0.1
2009	51	1.3	0.2
2010	50	1.3	0.2
2011	65	1.7	0.3
2012	65	1.7	0.3

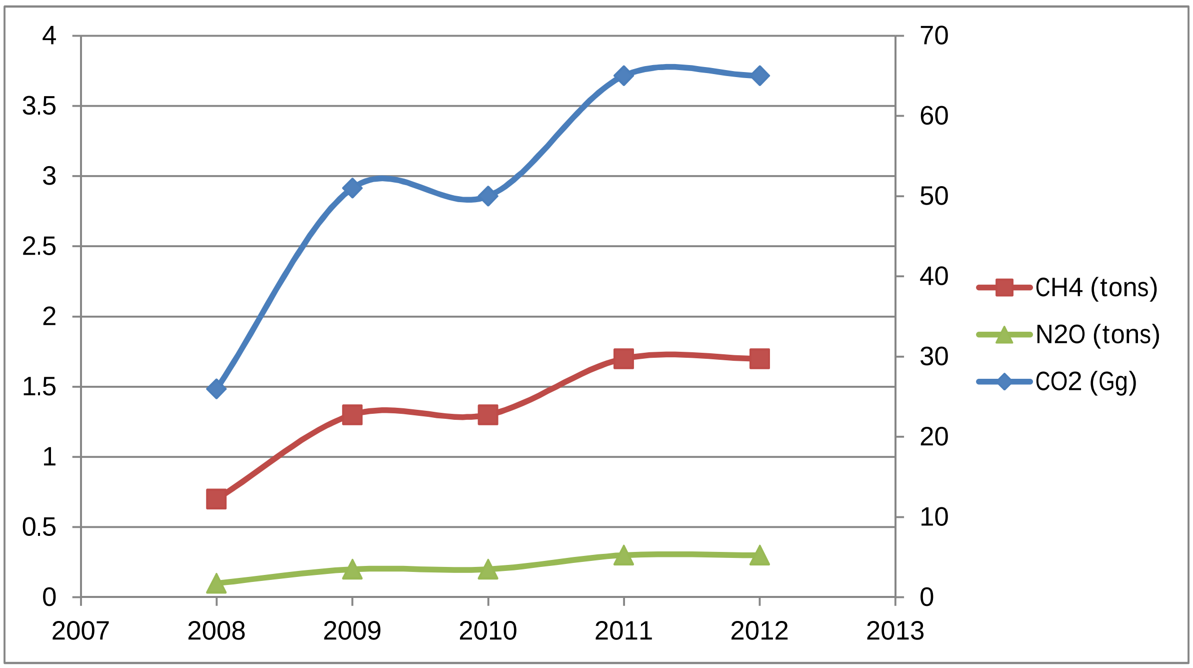


Figure 33 Scenario 8 - Greenhouse gas emissions for CO_2, CH_4 and N_20 (Yanbu)

Scenario 9 – 50% Natural Gas and 50% Fuel Oil.

The estimated greenhouse gas (GHG) emissions for CO_2, CH_4 and N_2O illustrated in **Table 30** and **Figure 34** for the years from 2008 to 2012. It was found that the highest CO_2, CH_4 and N_2O emissions from the actual fuel consumption data were 55 Gg (2009), 1.7 tons (2009) and 0.3 tons (2009-2010) respectively. The trend analysis shows that there is a 19 % more emission of CO_2 when the highest values of actual natural usage were compared with this scenario; hence this blend is a reasonably acceptable within a 20% window of acceptance.

Table 30 Scenario 9 – 50% Natural Gas and 50% Fuel Oil.

YEAR	CO_2 (Gg)	CH_4 (tons)	N_2O (tons)
2008	28	0.8	0.1
2009	55	1.7	0.3
2010	54	1.6	0.3
2011	70	2.1	0.4
2012	70	2.1	0.4

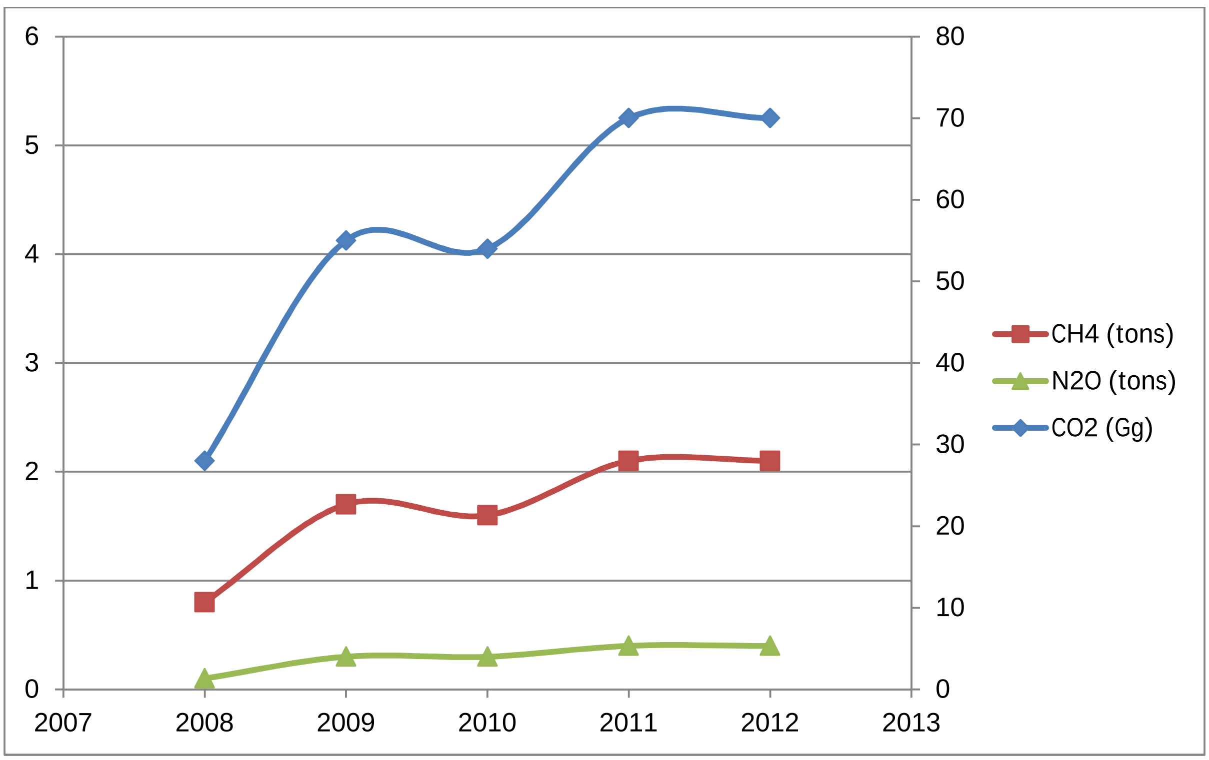


Figure 34 Scenario 9 - Greenhouse gas emissions for CO_2, CH_4 and N_20 (Yanbu)

Scenario10 – 70% Natural Gas and 30% Fuel Oil.

The estimated greenhouse gas (GHG) emissions for CO_2, CH_4 and N_2O illustrated in **Table 31** and **Figure 35** for the years from 2008 to 2012. It was found that the highest CO_2, CH_4 and N_2O emissions from the actual fuel consumption data were 52 Gg (2009), 1.3 tons (2009) and 0.2 tons (2009-2010) respectively. The trend analysis shows that there is a 11 % more emission of CO_2 when the highest values of actual natural usage were compared with this scenario; hence this blend is a reasonably acceptable within a 20% window of acceptance.

Table 31 Scenario10 – 70% Natural Gas and 30% Fuel Oil.

YEAR	CO_2 (Gg)	CH_4 (tons)	N_2O (tons)
2008	26	0.7	0.1
2009	52	1.3	0.2
2010	50	1.3	0.2
2011	66	1.7	0.3
2012	66	1.7	0.3

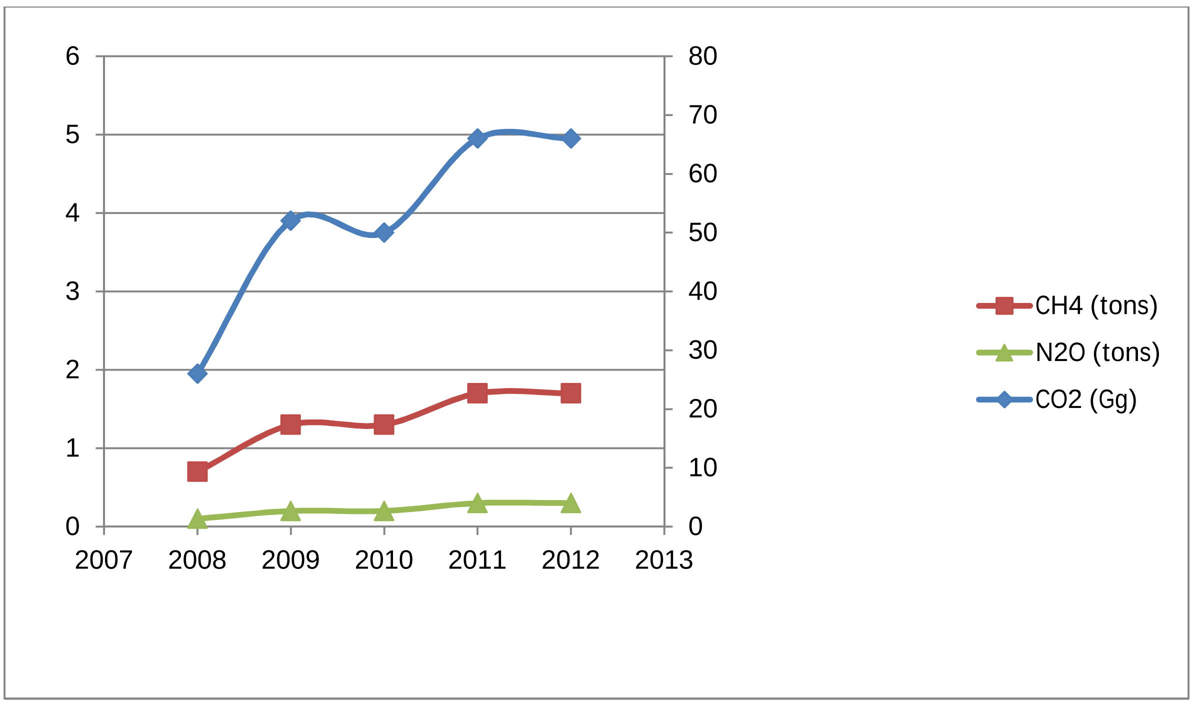


Figure 35 Scenario 10 - Greenhouse gas emissions for CO_2, CH_4 and N_20 (Yanbu)

EMISSION SCENARIOS FOR NON-GREENHOUSE GASES (NOX, CO, NMVOC, SO2) FOR PURE FUELS (YANBU)

Scenario 1 – 100% Natural Gas use (Normal Case)

The estimated non-greenhouse gas (non-GHG) emissions for as NO_X, CO, NMVOC and SO_2 are presented in **Table 32** and **Figure 36** for the years from 2000 to 2012. It was found that the highest NO_X, CO, NMVOC and SO_2 emissions from the actual fuel consumption data were 125 tons (2009), 17 tons (2009), 4 tons (2009-2010) and zero respectively. The consistent zero levels of SO_2 recorded is due to the absence of sulphur in Natural gas used in the industrial processes.

Table 32 Scenario 1 – 100% Natural Gas use (Normal Case)

YEAR	NOx (tons)	CO (tons)	NMVOC (tons)	SO_2 (tons)
2008	64	8	2	0
2009	125	17	4	0
2010	122	16	4	0
2011	159	21	5	0
2012	159	21	5	0

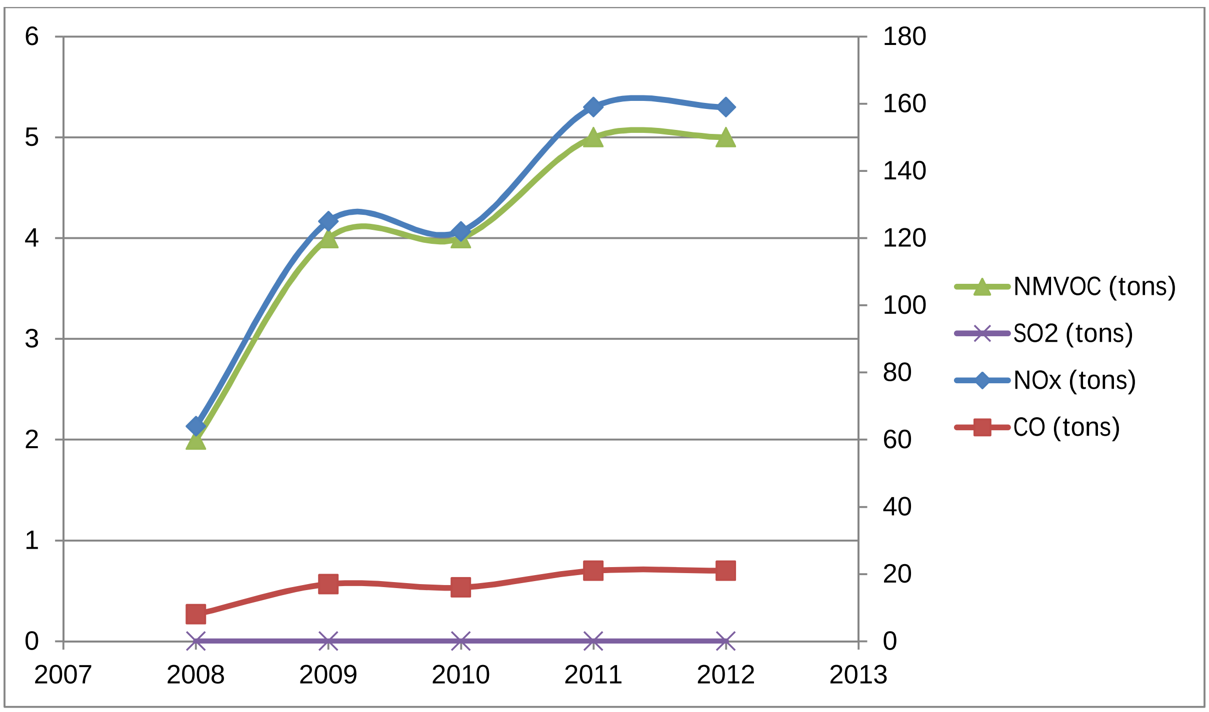


Figure 36 Scenario 1 - Non-Greenhouse emissions for NOx , CO , NMVOC and SO_2 (Yanbu)

Scenario 2 – 100% Crude Oil use (Worst Case)

The estimated non-greenhouse gas (non-GHG) emissions for as NO_X, CO, NMVOC and SO_2 are presented in **Table 33** and **Figure 37** for the years from 2000 to 2012. It was found that the highest NO_X, CO, NMVOC and SO_2 emissions from the actual fuel consumption data were 166 tons (2009), 12 tons (2009), zero and 781 tons (2009) respectively. The consistent zero levels of NMVOC recorded is due to the absence of NMVOC in Crude Oil used in the industrial processes while high level of SO_2 reflects the high levels of sulphur in Arabian Crude. The 100% crude oil used will lead to other pollution problems such as water, soil and human health problem (skin cancer and asthma). This option should be avoided in all usages due the sever impacts that threatening human health and environment.

Table 33 Scenario 2 – 100% Crude Oil use (Worst Case)

YEAR	NOx (tons)	CO (tons)	NMVOC (tons)	SO_2 (tons)
2008	85	6	0	398.4
2009	166	12	0	781
2010	163	12	0	765
2011	212	16	0	996.2
2012	212	16	0	996.2

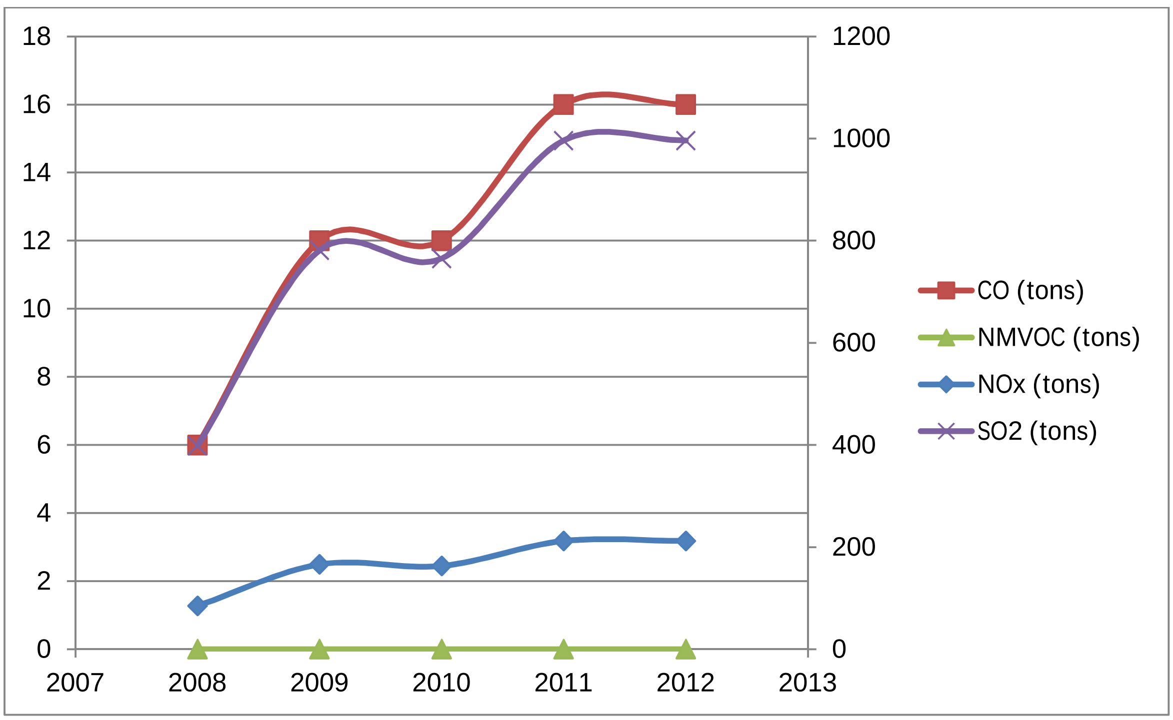


Figure 37 Scenario 2 - Non-Greenhouse emissions for NOx , CO , NMVOC and SO_2 (Yanbu)

Scenario 3 – 100% Diesel Fuel use

The estimated non-greenhouse gas (non-GHG) emissions for as NO_X, CO, NMVOC and SO_2 are presented in **Table 34** and **Figure 38** for the years from 2000 to 2012. It was found that the highest NO_X, CO, NMVOC and SO_2 emissions from the actual fuel consumption data were 166 tons (2009), 12 tons (2009-2010), 4 tons (2009-2010) and 383 tons (2009) respectively. The lowest NO_X, CO, NMVOC and SO_2 emissions were obtained as 85 tons (2008), tons (2000-2001), 925 tons (2000-2001) and 85435 tons (2000-2001) respectively

Table 34 Scenario 3 – 100% Diesel Fuel use

YEAR	NOx (tons)	CO (tons)	NMVOC (tons)	SO_2 (tons)
2008	85	6	2	195.6
2009	166	12	4	383
2010	162	12	4	375.6
2011	212	16	5	489
2012	212	16	5	489

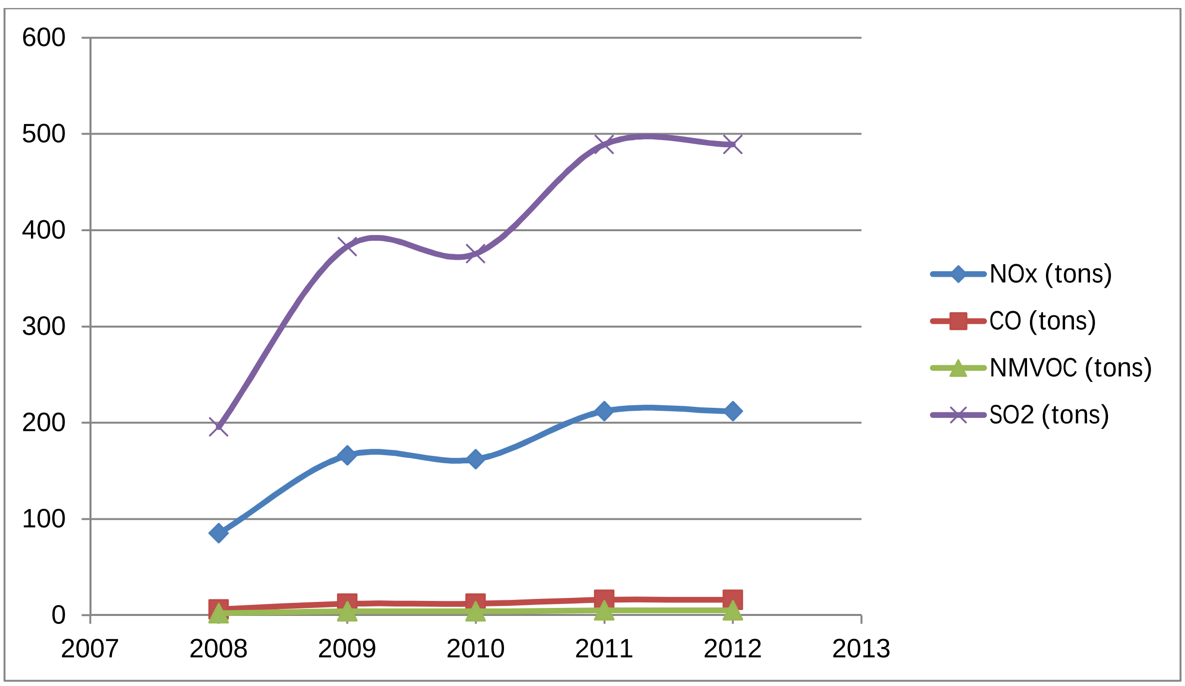


Figure 38 Scenario 3 - Non-Greenhouse emissions for NOx , CO , NMVOC and SO_2 (Yanbu)

Scenario 4 – 100% Fuel Oil use

The estimated non-greenhouse gas (non-GHG) emissions for as NO_X, CO, NMVOC and SO_2 are presented in **Table 35** and **Figure 39** for the years from 2000 to 2012. It was found that the highest NO_X, CO, NMVOC and SO_2 emissions from the actual fuel consumption data were 166 tons (2009), 12 tons (2009), 4 tons (2009) and 1446.6 tons (2009) respectively. While the forecasted data yielded 331 tons (2014), 25 tons (2014), 8 tons (2014) and 2878.5 tons (2014), respectively. The lowest NO_X, CO, NMVOC and SO_2 emissions were obtained as 85 tons (2008), 6 tons (2008), 2 tons (2008) and 738.1 tons (2009) respectively. Diesel and Fuel oil have almost the same emissions except for SO_2 due to their similar calorific value.

Table 35 Scenario 4 – 100% Fuel Oil use

YEAR	NOx (tons)	CO (tons)	NMVOC (tons)	SO_2 (tons)
2008	85	6	2	738.1
2009	166	12	4	1446.6
2010	163	12	4	1417.1
2011	212	16	5	1845.2
2012	212	16	5	1845.2

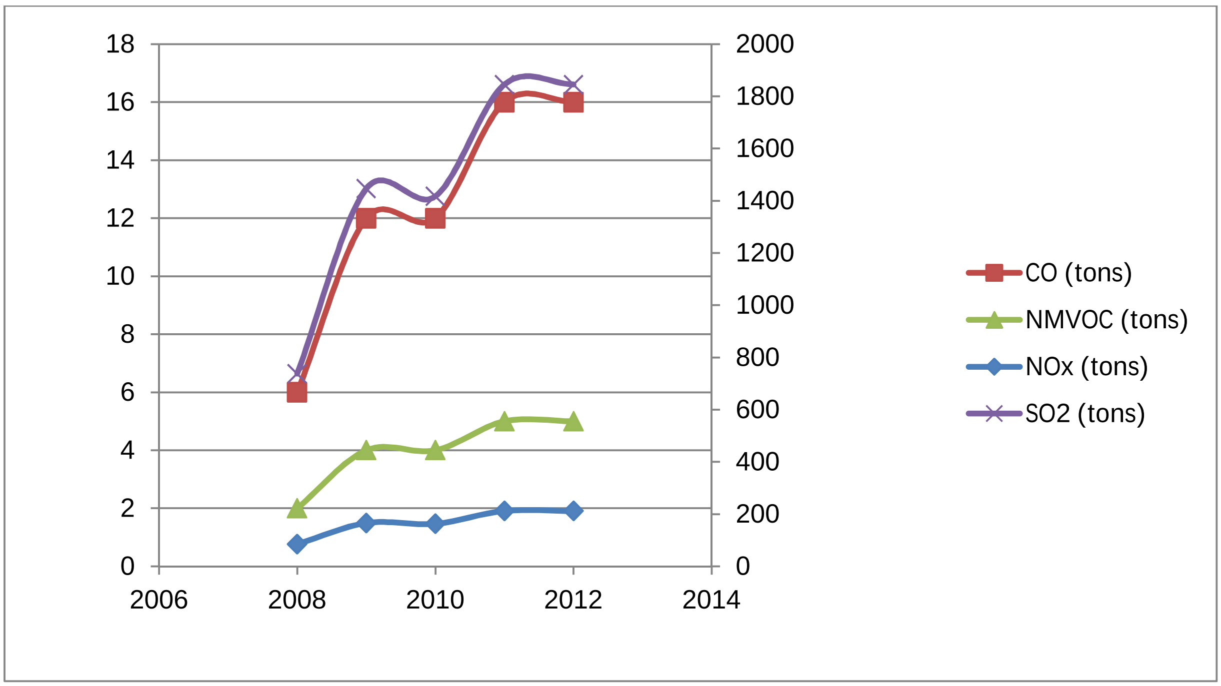


Figure 39 Scenario 4 - Non-Greenhouse emissions for NOx , CO , NMVOC and SO_2 (Yanbu)

EMISSION SCENARIOS WITH BLENDED FUELS (YANBU)

Scenario 5 – 50% Natural Gas and 50% Crude Oil Use.

The estimated non-greenhouse gas (non-GHG) emissions for as NO_X, CO, NMVOC and SO_2 are presented in **Table 36** and **Figure 40** for the years from 2000 to 2012. It was found that the highest NO_X, CO, NMVOC and SO_2 emissions from the actual fuel consumption data were 145 tons (2009), 15 tons (2009), 2 tons (2009-2010) and 390.5 tons (2009) respectively. The lowest NO_X, CO, NMVOC and SO_2 emissions were obtained as 74 tons (2008), 7 tons (2008), 1 tons (2008) and 199.2 tons (2008) respectively.

Table 36 Scenario 5 – 50% Natural Gas and 50% Crude Oil Use

YEAR	NOx (tons)	CO (tons)	NMVOC (tons)	SO_2 (tons)
2008	74	7	1	199.2
2009	145	15	2	390.5
2010	142	14	2	382.5
2011	185	19	3	498.1
2012	185	19	3	498.1

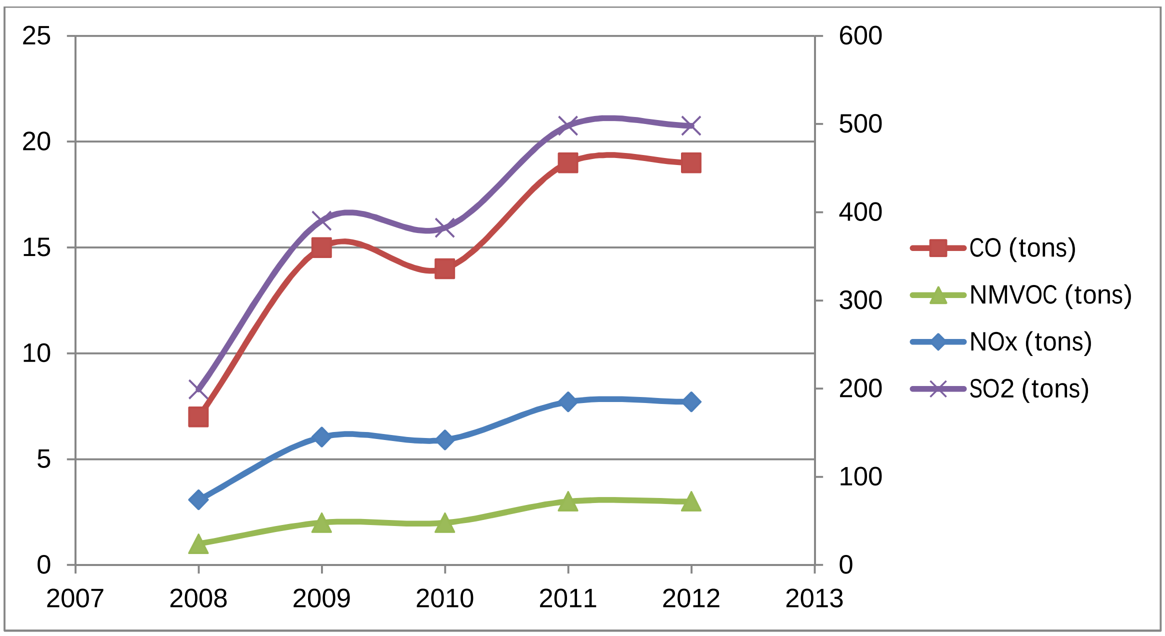


Figure 40 Scenario 5 - Non-Greenhouse emissions for NOx , CO , NMVOC and SO_2 (Yanbu)

Scenario 6 – 70% Natural Gas and 30% Crude Oil Use.

The estimated non-greenhouse gas (non-GHG) emissions for as NO_X, CO, NMVOC and are presented in **Table 37** and **Figure 41** for the years from 2000 to 2012. It was found that the highest NO_X, CO, NMVOC and SO_2 emissions from the actual fuel consumption data were 139 tons (2009), 15 tons (2009-2010), 3 tons (2009-2010) and 234 tons (2009) respectively. The lowest NO_X, CO, NMVOC and SO_2 emissions were obtained as 70tons (2008), 8 tons (2008), 1 tons (2008) and 119.5 tons (2008) respectively.

Table 37 Scenario 6 – 70% Natural Gas and 30% Crude Oil Use.

YEAR	NOx (tons)	CO (tons)	NMVOC (tons)	SO_2 (tons)
2008	70	8	1	119.5
2009	137	15	3	234
2010	134	15	3	229.5
2011	175	20	4	298.8
2012	175	20	4	298.8

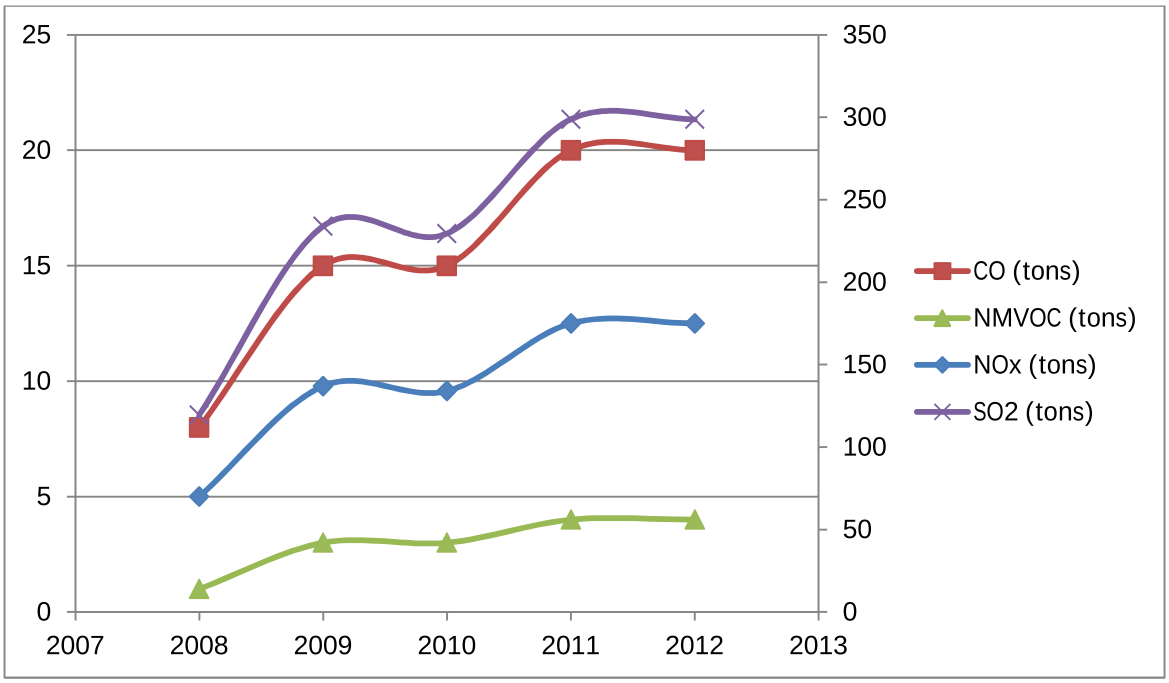


Figure 41 Scenario 6 - Non-Greenhouse emissions for NOx , CO , NMVOC and SO_2 (Yanbu)

Scenario 7 – 50% Natural Gas and 50% Diesel Use.

The estimated non-greenhouse gas (non-GHG) emissions for as NO_X, CO, NMVOC and SO_2 are presented in **Table 38** and **Figure 42** for the years from 2000 to 2012. It was found that the highest NO_X, CO, NMVOC and SO_2 emissions from the actual fuel consumption data were 145 tons (2009), 15 tons (2009), 4 tons (2009-2010) and 191.7 tons (2009) respectively. are presented in **Figure 16-19** for the years from 2000 to 2012. The lowest NO_X, CO, NMVOC and SO_2 emissions were obtained as 74 tons (2008), 7 tons (2008), 2 tons (2008) and 97.8 tons (2008) respectively.

Table 38 Scenario 7 – 50% Natural Gas and 50% Diesel Use.

YEAR	NOx (tons)	CO (tons)	NMVOC (tons)	SO_2 (tons)
2008	74	7	2	97.8
2009	145	15	4	191.7
2010	142	14	4	187.8
2011	185	19	5	244.5
2012	185	19	5	244.5

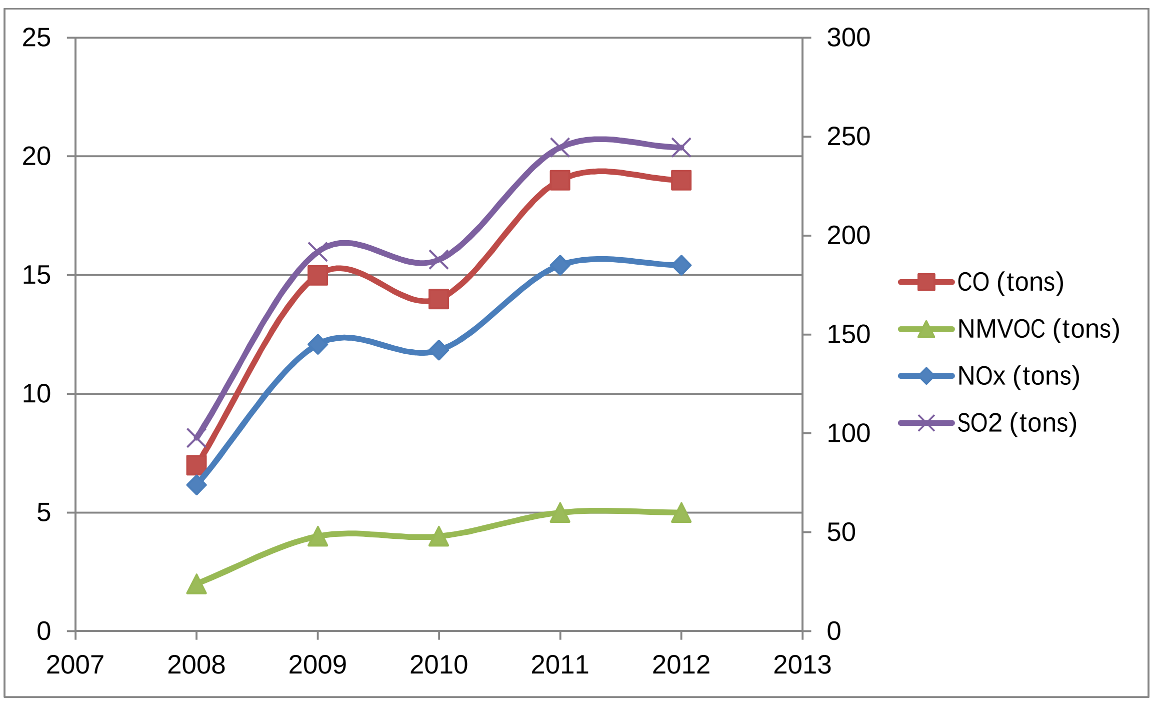


Figure 42 Scenario 7 - Non-Greenhouse emissions for NOx , CO , NMVOC and SO_2 (Yanbu)

Scenario 8 – 70% Natural Gas and 30% Diesel Use.

The estimated non-greenhouse gas (non-GHG) emissions for as NO_X, CO, NMVOC and SO_2 are presented in **Table 39** and **Figure 43** for the years from 2000 to 2012. It was found that the highest NO_X, CO, NMVOC and SO_2 emissions from the actual fuel consumption data were 137 tons (2009), 15 tons (2009), 4 tons (2009-2010) and 115 tons (2009) respectively. The lowest NO_X, CO, NMVOC and SO_2 emissions were obtained as 70 tons (2008), 8 tons (2008), 2 tons (2008) and 58.7 tons (2008) respectively.

Table 39 Scenario 8 – 70% Natural Gas and 30% Diesel Use.

YEAR	NOx (tons)	CO (tons)	NMVOC (tons)	SO_2 (tons)
2008	70	8	2	58.7
2009	137	15	4	115
2010	134	15	4	112.7
2011	175	20	5	146.7
2012	175	20	5	146.7

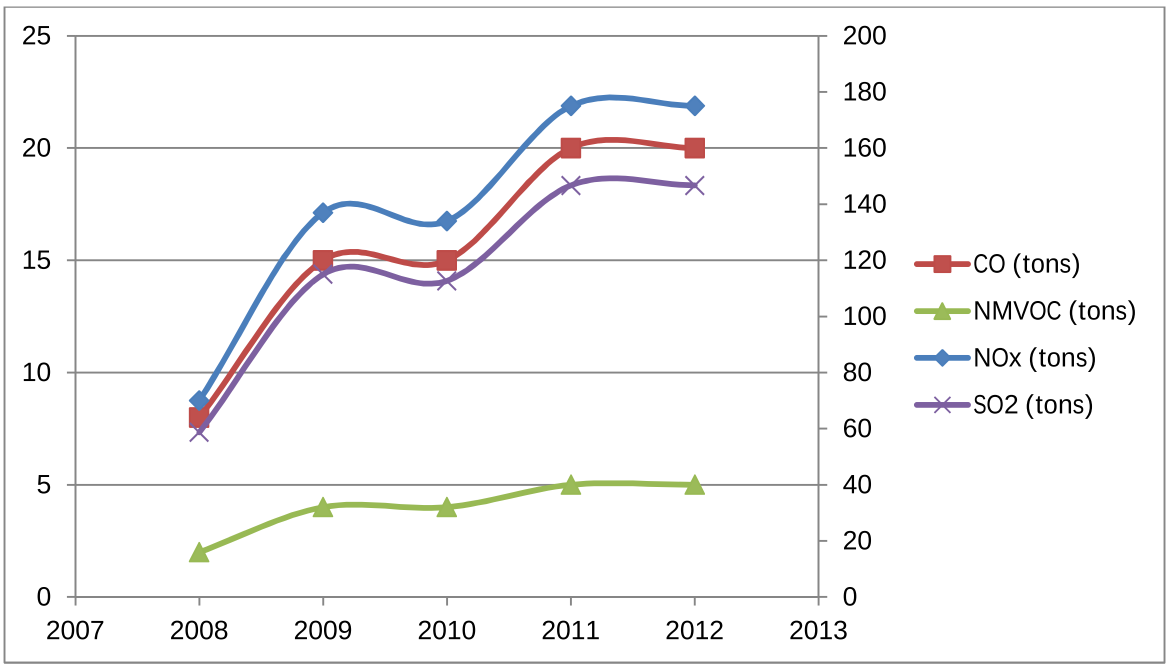


Figure 43 Scenario 8 - Non-Greenhouse emissions for NOx , CO , NMVOC and SO_2 (Yanbu)

Scenario 9 – 50% Natural Gas and 50% Fuel Oil Use.

The estimated non-greenhouse gas (non-GHG) emissions for as NO_X, CO, NMVOC and SO_2 are presented in **Table 40** and **Figure 44** for the years from 2000 to 2012. It was found that the highest NO_X, CO, NMVOC and SO_2 emissions from the actual fuel consumption data were 145 tons (2009), 15 tons (2009), 4 tons (2009-2010) and 723.3 tons (2009) respectively. The lowest NO_X, CO, NMVOC and SO_2 emissions were obtained as 74 tons (2008), 7 tons (2008), 2 tons (2008) and 369 tons (2008) respectively.

Table 40 Scenario 9 – 50% Natural Gas and 50% Fuel Oil Use

YEAR	NOx (tons)	CO (tons)	NMVOC (tons)	SO_2 (tons)
2008	74	7	2	369
2009	145	15	4	723.3
2010	142	14	4	708.5
2011	185	19	5	922.6
2012	185	19	5	922.6

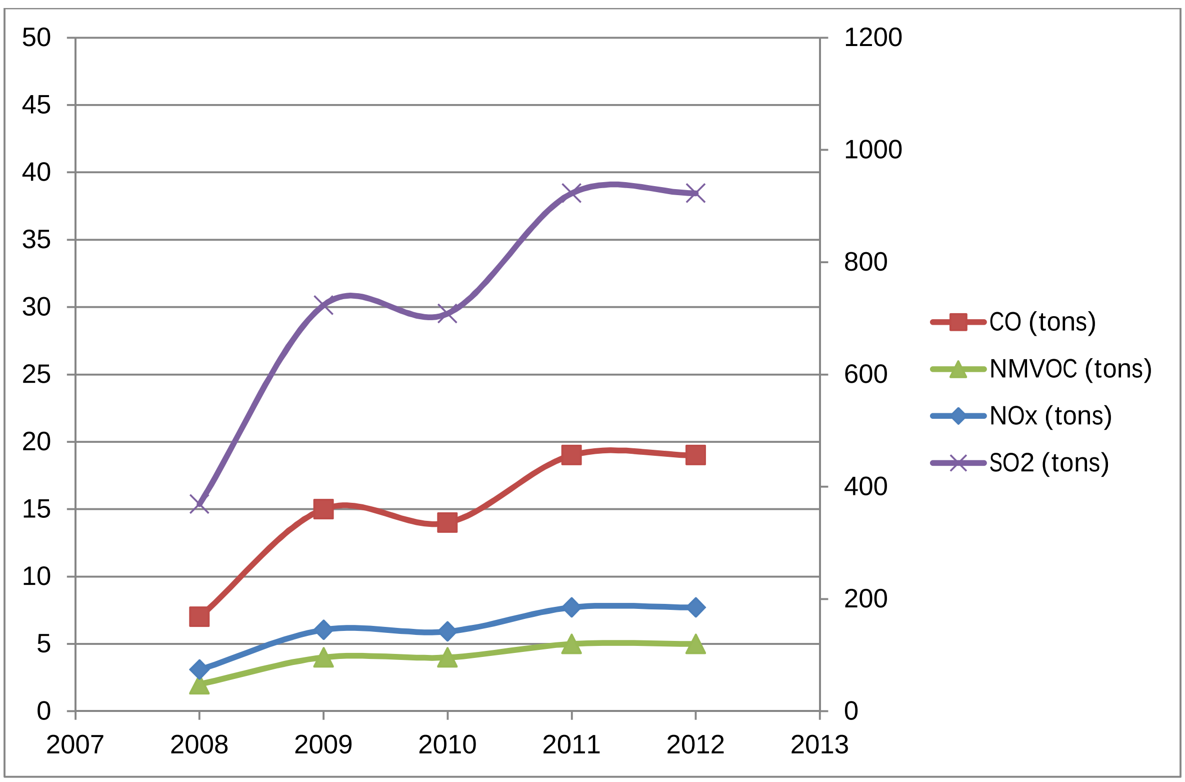


Figure 44 Scenario 9 - Non-Greenhouse emissions for NOx , CO , NMVOC and SO_2 (Yanbu)

Scenario 10 – 70% Natural Gas and 30% Fuel Oil Use.

The estimated non-greenhouse gas (non-GHG) emissions for as NO_X, CO, NMVOC and SO_2 are presented in **Table 41** and **Figure 45** for the years from 2000 to 2012. It was found that the highest NO_X, CO, NMVOC and SO_2 emissions from the actual fuel consumption data were 137 tons (2009), 15 tons (2009), 4 tons (2009-2010) and 434 tons (2009) respectively. The lowest NO_X, CO, NMVOC and SO_2 emissions were obtained as 70 tons (2008), 8 tons (2008), 2 tons (2008) and 221.4 tons (2008) respectively.

Table 41 Scenario 10 – 70% Natural Gas and 30% Fuel Oil Use.

YEAR	NOx (tons)	CO (tons)	NMVOC (tons)	SO_2 (tons)
2008	70	8	2	221.4
2009	137	15	4	434
2010	134	15	4	425.1
2011	175	20	5	553.5
2012	175	20	5	553.5

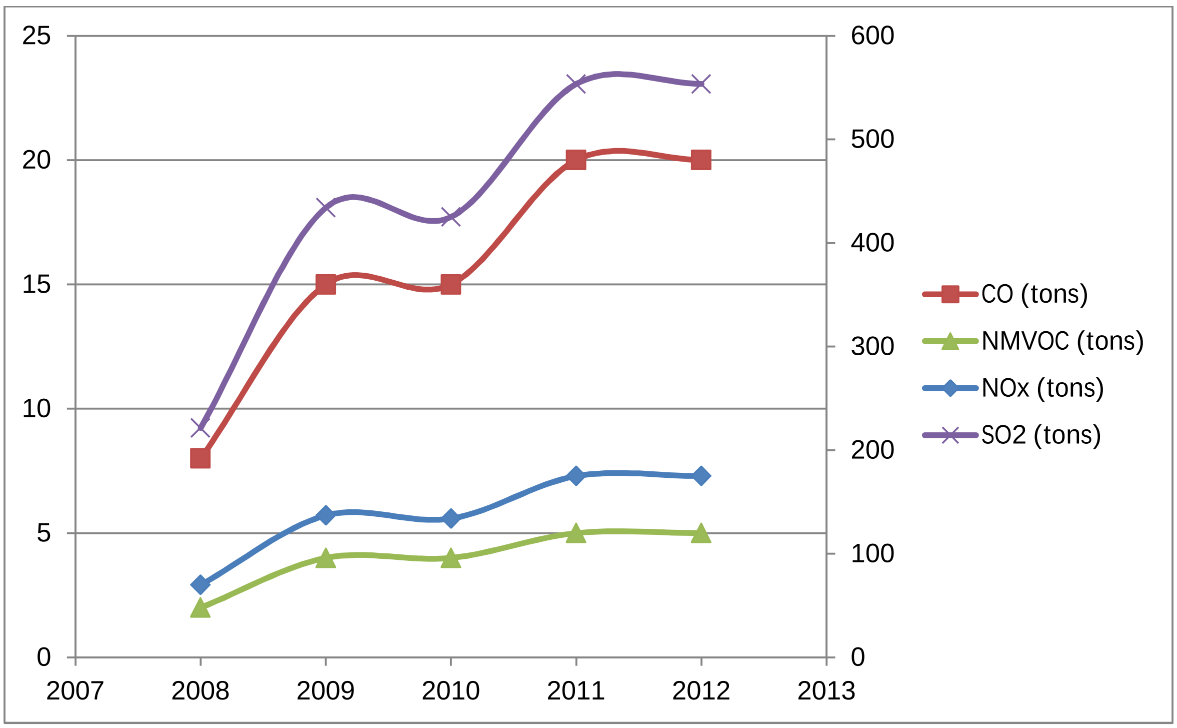


Figure 45 Scenario 10 - Non-Greenhouse emissions for NOx , CO , NMVOC and SO_2 (Yanbu)

CHAPTER 5

STATISTICAL ANALYSIS

The statistically analysis in this section is formulated based on the comparison of the emission generated by using pure natural gas with other fuels and presented as the performance of individual greenhouse (CO_2, CH_4 and N_2O) and non-greenhouse gases (NO_x , CO , NMVOC and SO_2).

The various scenarios are first compared using the Krustal-Wallis ANOVA on rank and when necessary, as in the case if significant difference is observed in the median values, Tukey all pairwise multiple comparison procedures is applied.

The desirable scenarios are those that do not show any significant difference when compared to levels of emission using 100% natural gas.

A result of "Do Not Test" occurs for a comparison when no significant difference is found between the two rank sums that enclose that comparison. For example, there are four rank sums sorted in order, and no significant difference between rank sums 4 vs. 2, then there would be no test 4 vs. 3 and 3 vs. 2, but still test 4 vs. 1 and 3 vs. 1 (4 vs. 3 and 3 vs. 2 are enclosed by 4 vs. 2: 4 3 2 1). Note that not testing the enclosed rank sums is a procedural rule, and a result of Do Not Test should be treated as if there is no significant difference between the rank sums, even though one may appear to exist.

Jubail

CO_2

The differences in the median values among the scenarios are not great enough to exclude the possibility that the difference is due to random sampling variability; there is not a statistically significant difference (P = 0.221) between the levels of CO_2 generated from burning of Natural gas at Jubail industrial city.

CH_4

The differences in the median values among scenarios are greater than would be expected by chance; there is a statistically significant difference (P = <0.001). To isolate the group or groups that differ from Scenario 1, Tukey method was applied .

Comparison	Diff of Ranks	q	P<0.05
Scenario 3 vs Scenario 1	1145.000	8.430	Yes
Scenario 2 vs Scenario 1	1144.000	8.422	Yes
Scenario 4 vs Scenario 1	1123.500	8.272	Yes
Scenario 7 vs Scenario 1	701.000	5.161	Yes
Scenario 9 vs Scenario 1	672.000	4.947	Yes
Scenario 5 vs Scenario 1	663.500	4.885	Yes
Scenario 8 vs Scenario 1	**403.500**	**2.971**	**No**
Scenario 6 vs Scenario 1	**401.500**	**2.956**	**Do Not Test**
Scenario 10 vs Scenario 1	**391.000**	**2.879**	**Do Not Test**

N_20

The differences in the median values among scenarios are greater than would be expected by chance; there is a statistically significant difference (P = <0.001). To isolate the group or groups that differ from Scenario 1, Tukey method was applied .

Comparison	Diff of Ranks	q	P<0.05
Scenario 2 vs Scenario 1	1309.000	9.637	Yes
Scenario 3 vs Scenario 1	1306.500	9.619	Yes
Scenario 4 vs Scenario 1	1284.500	9.457	Yes
Scenario 7 vs Scenario 1	789.500	5.813	Yes

Scenario 5 vs Scenario 1	781.500	5.754	Yes
Scenario 9 vs Scenario 1	768.500	5.658	Yes
Scenario 6 vs Scenario 1	**459.000**	**3.379**	**No**
Scenario 8 vs Scenario 1	**456.000**	**3.357**	**Do Not Test**
Scenario 10 vs Scenario 1	**450.500**	**3.317**	**Do Not Test**

NOx

The differences in the median values among scenarios are not great enough to exclude the possibility that the difference is due to random sampling variability; there is not a statistically significant difference (P = 0.208), between the levels of NOx generated from burning of Natural gas at Jubail industrial city

CO

The differences in the median values among scenarios are not great enough to exclude the possibility that the difference is due to random sampling variability; there is not a statistically significant difference (P = 0.097) , between the levels of CO generated from burning of Natural gas at Jubail industrial city

NMVOC

The differences in the median values among scenarios are greater than would be expected by chance; there is a statistically significant difference (P = <0.001). To isolate the group or groups that differ from Scenario 1, Tukey method was applied .

All Pairwise Multiple Comparison Procedures (Tukey Test):

Comparison	Diff of Ranks	q	P<0.05
Scenario 8 vs Scenario 1	**3.000**	**0.0221**	**Do Not Test**
Scenario 7 vs Scenario 1	**0.000**	**0.000**	**Do Not Test**
Scenario 1 vs Scenario 2	980.500	7.219	Yes
Scenario 1 vs Scenario 5	707.500	5.209	Yes
Scenario 1 vs Scenario 6	**436.500**	**3.214**	**Do Not Test**
Scenario 1 vs Scenario 3	**32.000**	**0.236**	**Do Not Test**
Scenario 1 vs Scenario 4	**31.500**	**0.232**	**Do Not Test**
Scenario 1 vs Scenario 9	**9.000**	**0.0663**	**Do Not Test**

Scenario 1 vs Scenario 10	**6.000**	**0.0442**	**Do Not Test**

SO_2

The differences in the median values among scenarios are greater than would be expected by chance; there is a statistically significant difference ($P = <0.001$). To isolate the group or groups that differ from Scenario 1, Tukey method was applied .

Comparison	**Diff of Ranks**	**q**	**P<0.05**
Scenario 3 vs Scenario 1	1145.000	8.430	Yes
Scenario 2 vs Scenario 1	1144.000	8.422	Yes
Scenario 4 vs Scenario 1	1123.500	8.272	Yes
Scenario 7 vs Scenario 1	701.000	5.161	Yes
Scenario 9 vs Scenario 1	672.000	4.947	Yes
Scenario 5 vs Scenario 1	663.500	4.885	Yes
Scenario 8 vs Scenario 1	**403.500**	**2.971**	**No**
Scenario 6 vs Scenario 1	**401.500**	**2.956**	**Do Not Test**
Scenario 10 vs Scenario 1	**391.000**	**2.879**	**Do Not Test**

Yanbu

CO_2

The differences in the median values among the scenarios are not great enough to exclude the possibility that the difference is due to random sampling variability; there is not a statistically significant difference (P = 0.543) between the levels of CO_2 generated from burning of Natural gas at Yanbu industrial city.

CH_4

The differences in the median values among scenarios are greater than would be expected by chance; there is a statistically significant difference (P = <0.001). To isolate the group or groups that differ from Scenario 1, Tukey method was applied .

Comparison	Diff of Ranks	q	P<0.05
100% CO vs 100% NG	156.000	4.786	Yes
100% DO vs 100% NG	156.000	4.786	Yes
100% FO vs 100% NG	156.000	4.786	Yes
50% NG VS 50% FO vs 100% NG	**92.500**	**2.838**	**No**
50% NG VS 50% CO vs 100% NG	**92.500**	**2.838**	**Do Not Test**
50% NG VS 50% DO vs 100% NG	**80.000**	**2.454**	**Do Not Test**
70% NG VS 30% CO vs 100% NG	**54.000**	**1.657**	**Do Not Test**
70% NG VS 30% DO vs 100% NG	**54.000**	**1.657**	**Do Not Test**

N_20

The differences in the median values among scenarios are greater than would be expected by chance; there is a statistically significant difference (P = <0.001). To isolate the group or groups that differ from Scenario 1, Tukey method was applied .

Comparison	Diff of Ranks	q	P<0.05
100% CO vs 100% NG	176.000	5.399	Yes
100% DO vs 100% NG	176.000	5.399	Yes
100% FO vs 100% NG	176.000	5.399	Yes
50% NG VS 50% FO vs 100% NG	**100.500**	**3.083**	**No**
50% NG VS 50% DO vs 100% NG	**100.500**	**3.083**	**Do Not Test**
50% NG VS 50% CO vs 100% NG	**100.500**	**3.083**	**Do Not Test**
70% NG VS 30% CO vs 100% NG	**58.500**	**1.795**	**Do Not Test**

70% NG VS 30% DO vs 100% NG	**58.500**	**1.795**	**Do Not Test**
70% NG VS 30% FO vs 100% NG	**58.500**	**1.795**	**Do Not Test**

NOx

The differences in the median values among scenarios are not great enough to exclude the possibility that the difference is due to random sampling variability; there is not a statistically significant difference (P = 0.565), between the levels of NOx generated from burning of Natural gas at Yanbu industrial city

CO

The differences in the median values among scenarios are not great enough to exclude the possibility that the difference is due to random sampling variability; there is not a statistically significant difference (P = 0.662) , between the levels of CO generated from burning of Natural gas at Yanbu industrial city

NMVOC

The differences in the median values among scenarios are greater than would be expected by chance; there is a statistically significant difference (P = <0.007). To isolate the group or groups that differ from Scenario 1, Tukey method was applied .

Comparison	Diff of Ranks	q	P<0.05
50% NG VS 50% FO vs 100% NG	0.000	0.000	Do Not Test
70% NG VS 30% DO vs 100% NG	0.000	0.000	Do Not Test
50% NG VS 50% DO vs 100% NG	0.000	0.000	Do Not Test
100% NG vs 100% CO	141.000	4.326	Do Not Test
100% NG vs 50% NG VS 50% CO	88.500	2.715	Do Not Test
100% NG vs 70% NG VS 30% CO	55.500	1.703	Do Not Test
100% NG vs 100% DO	0.000	0.000	Do Not Test
100% NG vs 100% FO	0.000	0.000	Do Not Test
100% NG vs 70% NG VS 30% FO	0.000	0.000	Do Not Test

SO_2

The differences in the median values among scenarios are greater than would be expected by chance; there is a statistically significant difference (P = <0.001). To isolate the group or groups that differ from Scenario 1, Tukey method was applied .

Comparison	**Diff of Ranks**	**q**	**P<0.05**
100% FO vs 100% NG	219.000	6.719	Yes
100% CO vs 100% NG	188.000	5.768	Yes
50% NG VS 50% FO vs 100% NG	173.000	5.307	Yes
70% NG VS 30% FO vs 100% NG	**136.000**	**4.172**	**No**
50% NG VS 50% CO vs 100% NG	**124.000**	**3.804**	**Do Not Test**
100% DO vs 100% NG	**117.000**	**3.589**	**Do Not Test**
70% NG VS 30% CO vs 100% NG	**77.000**	**2.362**	**Do Not Test**
50% NG VS 50% DO vs 100% NG	**60.000**	**1.841**	**Do Not Test**
70% NG VS 30% DO vs 100% NG	**31.000**	**0.951**	**Do Not Test**

CHAPTER 6

SUMMARY AND CONCLUSIONS

This thesis work describes greenhouse gases and non-greenhouse gas emissions using different fuel scenarios and priority processing to identify the best choice of fuel substitute in case of shortfall in the supply of natural gas. The emissions of the "Kyoto greenhouse gases" i.e. CO_2, CH_4, N_2O for Jubail and Yanbu based on the estimated fuel values were subjected to Krustal-Wallis One Way Analysis of Variance on Ranks. No individual scenario resulted in an overall decrease in the level of greenhouse gases emissions. However, the result obtained is valuable in formulating a generalize baseline for greenhouse gases emissions in the industrial cities.

The data obtain for carbon dioxide (CO_2), appears to be largely different (values) but of no statistical significance. The other greenhouse gases methane (CH_4) and nitrous oxide (N_2O) show statistically significant differences. The global warming potential (GWP) of methane is 72 times more effective to trap heat that carbon. Nitrous oxide is 289 more effective than carbon dioxide. GWP is expressed as a factor of carbon dioxide (whose GWP is standardized to 1). Our conclusions are hence, based on the significant differences in the levels of methane and nitrous oxide. Further judgment were arrived at by comparing the levels of non-greenhouse gases which are statistically significantly different.

Generally, blended fuel scenarios gave reduction in levels of Greenhouse gases emissions as would have been expected but Scenarios **6**, **8** and **10** gave a promising replacement fuel in the event Natural gas shortfall while the other six scenarios tailed along . The scenarios were also ranked according to their performance in the levels of non-greenhouse gases, which include NO_x, CO, NMVOC and SO_2. Scenario 6 ranked first above the 100% natural gas consideration as the best fuel. Scenarios **2,4,8** and **10** were on the borderline while scenarios **3, 5, 7 and 9** are at the bottom of the ranking table. Overall, scenarios **6, 8** and **10** represent the best substitute blends in consideration of their greenhouse and non-greenhouse emissions.

Environmental problems especially air pollution is the most significant impact on air quality in the industrial cities. Proper selection of Substitute fuel based on lower emission will preserve the air quality and environment and also the proper implementation and management of the scenarios can be helpful in sustainable developments and economically beneficial.

CHAPTER 7

RECOMMEDATIONS

- It is recommend the use of substitute fuels
  - **Scenarios 6 (*70% Natural Gas + 30% Crude Oil*)**,
  - **Scenarios 8 (*70% Natural Gas + 30% Diesel*)** and
  - **Scenarios 10 (*70% Natural Gas + 30% Fuel Oil*)**
- It is recommended that the usage of heavy oils such as fuel oil should be avoided, based on the findings of this work (high emissions with significant impact on the environment)
- It is recommended that further studies should be carried out using TIER 2 & 3 IPCC methodology to develop national inventory for Saudi Arabia due to high accuracy
- Proper selection of Substitute fuel based on lower emission will contribute positively in the mitigation of global environmental concerns
- Proper implementation and management will be beneficial environmentally, socially and economically as well as create compliance with sustainable developmental goals.
- RCJY needs to revise its mission and vision which encourages the development energy intensive industries
- For future industrial expansion RCJY need to look for less energy-intensive industries willing to contribute to the Kingdom's growth

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APPENDIXES

JUBAIL

CO_2

Kruskal-Wallis One Way Analysis of Variance on Ranks

Data source: CO2 in GHG FINAL 2000-2012

Group	N	Missing	Median	25%	75%
Scenario 1	13	0	14616.000	12227.750	20929.000
Scenario 2	13	0	19009.000	15903.500	27220.750
Scenario 3	13	0	19199.000	16062.000	27492.750
Scenario 4	13	0	20055.000	16216.000	28718.500
Scenario 5	13	0	16812.000	14065.750	24075.250
Scenario 6	13	0	15934.000	13329.750	22816.500
Scenario 7	13	0	16907.000	14144.750	24211.000
Scenario 8	13	0	15991.000	13391.750	22898.500
Scenario 9	13	0	17335.000	14210.500	24823.250
Scenario 10	13	0	16247.000	13420.250	23266.000

H = 11.867 with 9 degrees of freedom. (P = 0.221)

The differences in the median values among scenariosare not great enough to exclude the possibility that the difference is due to random sampling variability; there is not a statistically significant difference (P = 0.221)

CH_4

Kruskal-Wallis One Way Analysis of Variance on Ranks

Data source: CH4. in GHG FINAL 2000-2012

Group	N	Missing	Median	25%	75%
Scenario 1	13	0	262.000	218.750	375.250
Scenario 2	13	0	786.000	657.000	1124.500
Scenario 3	13	0	786.000	657.000	1124.500
Scenario 4	13	0	786.000	634.750	1124.500
Scenario 5	13	0	521.000	438.250	750.000
Scenario 6	13	0	419.000	350.250	600.250
Scenario 7	13	0	537.000	442.000	750.000
Scenario 8	13	0	419.000	354.000	600.250
Scenario 9	13	0	524.000	427.000	750.000
Scenario 10	13	0	419.000	343.500	600.250

H = 71.950 with 9 degrees of freedom. (P = <0.001)

The differences in the median values among scenariosare greater than would be expected by chance; there is a statistically significant difference (P = <0.001)

To isolate the group or groups that differ from the others use a multiple comparison procedure.

All Pairwise Multiple Comparison Procedures (Tukey Test):

Comparison	Diff of Ranks	q	P<0.05
Scenario 3 vs Scenario 1	1145.000	8.430	Yes
Scenario 3 vs Scenario 10	754.000	5.551	Yes
Scenario 3 vs Scenario 6	743.500	5.474	Yes
Scenario 3 vs Scenario 8	741.500	5.459	Yes
Scenario 3 vs Scenario 5	481.500	3.545	No
Scenario 3 vs Scenario 9	473.000	3.482	Do Not Test
Scenario 3 vs Scenario 7	444.000	3.269	Do Not Test
Scenario 3 vs Scenario 4	21.500	0.158	Do Not Test
Scenario 3 vs Scenario 2	1.000	0.00736	Do Not Test
Scenario 2 vs Scenario 1	1144.000	8.422	Yes
Scenario 2 vs Scenario 10	753.000	5.544	Yes
Scenario 2 vs Scenario 6	742.500	5.466	Yes
Scenario 2 vs Scenario 8	740.500	5.452	Yes
Scenario 2 vs Scenario 5	480.500	3.538	Do Not Test
Scenario 2 vs Scenario 9	472.000	3.475	Do Not Test
Scenario 2 vs Scenario 7	443.000	3.261	Do Not Test
Scenario 2 vs Scenario 4	20.500	0.151	Do Not Test
Scenario 4 vs Scenario 1	1123.500	8.272	Yes
Scenario 4 vs Scenario 10	732.500	5.393	Yes
Scenario 4 vs Scenario 6	722.000	5.316	Yes
Scenario 4 vs Scenario 8	720.000	5.301	Yes
Scenario 4 vs Scenario 5	460.000	3.387	Do Not Test
Scenario 4 vs Scenario 9	451.500	3.324	Do Not Test
Scenario 4 vs Scenario 7	422.500	3.111	Do Not Test
Scenario 7 vs Scenario 1	701.000	5.161	Yes

Scenario 7 vs Scenario 10	310.000	2.282	No
Scenario 7 vs Scenario 6	299.500	2.205	Do Not Test
Scenario 7 vs Scenario 8	297.500	2.190	Do Not Test
Scenario 7 vs Scenario 5	37.500	0.276	Do Not Test
Scenario 7 vs Scenario 9	29.000	0.214	Do Not Test
Scenario 9 vs Scenario 1	672.000	4.947	Yes
Scenario 9 vs Scenario 10	281.000	2.069	Do Not Test
Scenario 9 vs Scenario 6	270.500	1.991	Do Not Test
Scenario 9 vs Scenario 8	268.500	1.977	Do Not Test
Scenario 9 vs Scenario 5	8.500	0.0626	Do Not Test
Scenario 5 vs Scenario 1	663.500	4.885	Yes
Scenario 5 vs Scenario 10	272.500	2.006	Do Not Test
Scenario 5 vs Scenario 6	262.000	1.929	Do Not Test
Scenario 5 vs Scenario 8	260.000	1.914	Do Not Test
Scenario 8 vs Scenario 1	403.500	2.971	No
Scenario 8 vs Scenario 10	12.500	0.0920	Do Not Test
Scenario 8 vs Scenario 6	2.000	0.0147	Do Not Test
Scenario 6 vs Scenario 1	401.500	2.956	Do Not Test
Scenario 6 vs Scenario 10	10.500	0.0773	Do Not Test
Scenario 10 vs Scenario 1	391.000	2.879	Do Not Test

Note: The multiple comparisons on ranks do not include an adjustment for ties.

A result of "Do Not Test" occurs for a comparison when no significant difference is found between the two rank sums that enclose that comparison. For example, if you had four rank sums sorted in order, and found no significant difference between rank sums 4 vs. 2, then you would not test 4 vs. 3 and 3 vs. 2, but still test 4 vs. 1 and 3 vs. 1 (4 vs. 3 and 3 vs. 2 are enclosed by 4 vs. 2: 4 3 2 1). Note that not testing the enclosed rank sums is a procedural rule, and a result of Do Not Test should be treated as if there is no significant difference between the rank sums, even though one may appear to exist.

N_2O

Kruskal-Wallis One Way Analysis of Variance on Ranks

Data source: N2O in GHG FINAL 2000-2012

Group	N	Missing	Median	25%	75%
Scenario 1	13	0	26.000	21.750	37.250
Scenario 2	13	0	157.000	131.750	225.000
Scenario 3	13	0	157.000	131.500	225.000
Scenario 4	13	0	157.000	127.000	225.000
Scenario 5	13	0	92.000	77.000	131.500
Scenario 6	13	0	66.000	54.500	93.500
Scenario 7	13	0	92.000	80.750	131.500
Scenario 8	13	0	66.000	54.500	93.500
Scenario 9	13	0	92.000	74.750	131.500
Scenario 10	13	0	66.000	53.750	94.250

H = 93.995 with 9 degrees of freedom. (P = <0.001)

The differences in the median values among scenariosare greater than would be expected by chance; there is a statistically significant difference (P = <0.001)

To isolate the group or groups that differ from the others use a multiple comparison procedure.

All Pairwise Multiple Comparison Procedures (Tukey Test):

Comparison	Diff of Ranks	q	P<0.05
Scenario 2 vs Scenario 1	1309.000	9.637	Yes
Scenario 2 vs Scenario 10	858.500	6.321	Yes
Scenario 2 vs Scenario 8	853.000	6.280	Yes
Scenario 2 vs Scenario 6	850.000	6.258	Yes
Scenario 2 vs Scenario 9	540.500	3.979	No
Scenario 2 vs Scenario 5	527.500	3.884	Do Not Test
Scenario 2 vs Scenario 7	519.500	3.825	Do Not Test
Scenario 2 vs Scenario 4	24.500	0.180	Do Not Test
Scenario 2 vs Scenario 3	2.500	0.0184	Do Not Test
Scenario 3 vs Scenario 1	1306.500	9.619	Yes
Scenario 3 vs Scenario 10	856.000	6.302	Yes
Scenario 3 vs Scenario 8	850.500	6.262	Yes
Scenario 3 vs Scenario 6	847.500	6.240	Yes
Scenario 3 vs Scenario 9	538.000	3.961	Do Not Test
Scenario 3 vs Scenario 5	525.000	3.865	Do Not Test
Scenario 3 vs Scenario 7	517.000	3.806	Do Not Test
Scenario 3 vs Scenario 4	22.000	0.162	Do Not Test
Scenario 4 vs Scenario 1	1284.500	9.457	Yes
Scenario 4 vs Scenario 10	834.000	6.140	Yes
Scenario 4 vs Scenario 8	828.500	6.100	Yes
Scenario 4 vs Scenario 6	825.500	6.078	Yes
Scenario 4 vs Scenario 9	516.000	3.799	Do Not Test
Scenario 4 vs Scenario 5	503.000	3.703	Do Not Test
Scenario 4 vs Scenario 7	495.000	3.644	Do Not Test
Scenario 7 vs Scenario 1	789.500	5.813	Yes
Scenario 7 vs Scenario 10	339.000	2.496	No

Scenario 7 vs Scenario 8	333.500	2.455	Do Not Test
Scenario 7 vs Scenario 6	330.500	2.433	Do Not Test
Scenario 7 vs Scenario 9	21.000	0.155	Do Not Test
Scenario 7 vs Scenario 5	8.000	0.0589	Do Not Test
Scenario 5 vs Scenario 1	781.500	5.754	Yes
Scenario 5 vs Scenario 10	331.000	2.437	Do Not Test
Scenario 5 vs Scenario 8	325.500	2.396	Do Not Test
Scenario 5 vs Scenario 6	322.500	2.374	Do Not Test
Scenario 5 vs Scenario 9	13.000	0.0957	Do Not Test
Scenario 9 vs Scenario 1	768.500	5.658	Yes
Scenario 9 vs Scenario 10	318.000	2.341	Do Not Test
Scenario 9 vs Scenario 8	312.500	2.301	Do Not Test
Scenario 9 vs Scenario 6	309.500	2.279	Do Not Test
Scenario 6 vs Scenario 1	459.000	3.379	No
Scenario 6 vs Scenario 10	8.500	0.0626	Do Not Test
Scenario 6 vs Scenario 8	3.000	0.0221	Do Not Test
Scenario 8 vs Scenario 1	456.000	3.357	Do Not Test
Scenario 8 vs Scenario 10	5.500	0.0405	Do Not Test
Scenario 10 vs Scenario 1	450.500	3.317	Do Not Test

Note: The multiple comparisons on ranks do not include an adjustment for ties.

A result of "Do Not Test" occurs for a comparison when no significant difference is found between the two rank sums that enclose that comparison. For example, if you had four rank sums sorted in order, and found no significant difference between rank sums 4 vs. 2, then you would not test 4 vs. 3 and 3 vs. 2, but still test 4 vs. 1 and 3 vs. 1 (4 vs. 3 and 3 vs. 2 are enclosed by 4 vs. 2: 4 3 2 1). Note that not testing the enclosed rank sums is a procedural rule, and a result of Do Not Test should be treated as if there is no significant difference between the rank sums, even though one may appear to exist.

NOx

Kruskal-Wallis One Way Analysis of Variance on Ranks

Data source: NOx in GHG FINAL 2000-2012

Group	N	Missing	Median	25%	75%
Scenario 1	13	0	39275.000	32858.000	56241.500
Scenario 2	13	0	52367.000	43810.750	74988.750
Scenario 3	13	0	52367.000	43810.500	74988.750
Scenario 4	13	0	52367.000	42343.500	74988.750
Scenario 5	13	0	45821.000	38334.250	65615.000
Scenario 6	13	0	43203.000	36144.000	61865.500
Scenario 7	13	0	45821.000	38334.250	64265.000
Scenario 8	13	0	43203.000	36144.000	61865.500
Scenario 9	13	0	45821.000	37584.250	65615.000
Scenario 10	13	0	43203.000	35694.000	61865.500

H = 12.098 with 9 degrees of freedom. (P = 0.208)

The differences in the median values among scenariosare not great enough to exclude the possibility that the difference is due to random sampling variability; there is not a statistically significant difference (P = 0.208)

CO

Kruskal-Wallis One Way Analysis of Variance on Ranks

Data source: CO in GHG FINAL 2000-2012

Group	**N**	**Missing**	**Median**	**25%**	**75%**
Scenario 1	13	0	5237.000	4381.250	7498.500
Scenario 2	13	0	3928.000	3286.000	5624.000
Scenario 3	13	0	3928.000	3286.000	5624.000
Scenario 4	13	0	3928.000	3175.750	5624.000
Scenario5	13	0	4582.000	3795.750	6561.750
Scenario 6	13	0	4844.000	4052.750	6936.250
Scenario 7	13	0	4582.000	3833.250	6561.750
Scenario 8	13	0	4844.000	4052.750	6936.250
Scenario 9	13	0	4582.000	3777.000	6561.750
Scenario10	13	0	4844.000	4019.000	6936.250

H = 14.776 with 9 degrees of freedom. (P = 0.097)

The differences in the median values among scenariosare not great enough to exclude the possibility that the difference is due to random sampling variability; there is not a statistically significant difference (P = 0.097)

NMVOC

Kruskal-Wallis One Way Analysis of Variance on Ranks

Data source: NMVOC in GHG FINAL 2000-2012

Group	N	Missing	Median	25%	75%
Scenario 1	13	0	1309.000	1095.000	1874.500
Scenario 2	13	0	0.000	0.000	0.000
Scenario 3	13	0	1265.000	1095.000	1874.500
Scenario 4	13	0	1309.000	1058.500	1874.500
Scenario 5	13	0	655.000	548.000	937.500
Scenario 6	13	0	916.000	766.750	1312.250
Scenario 7	13	0	1309.000	1095.000	1874.500
Scenario 8	13	0	1309.000	1095.000	1873.500
Scenario 9	13	0	1309.000	1076.250	1874.500
Scenario 10	13	0	1309.000	1083.750	1874.500

H = 63.676 with 9 degrees of freedom. (P = <0.001)

The differences in the median values among scenariosare greater than would be expected by chance; there is a statistically significant difference (P = <0.001)

To isolate the group or groups that differ from the others use a multiple comparison procedure.

All Pairwise Multiple Comparison Procedures (Tukey Test):

Comparison	Diff of Ranks	q	P<0.05
Scenario 8 vs Scenario 2	983.500	7.241	Yes
Scenario 8 vs Scenario 5	710.500	5.231	Yes
Scenario 8 vs Scenario 6	439.500	3.236	No
Scenario 8 vs Scenario 3	35.000	0.258	Do Not Test
Scenario 8 vs Scenario 4	34.500	0.254	Do Not Test
Scenario 8 vs Scenario 9	12.000	0.0883	Do Not Test
Scenario 8 vs Scenario 10	9.000	0.0663	Do Not Test
Scenario 8 vs Scenario 1	3.000	0.0221	Do Not Test
Scenario 8 vs Scenario 7	3.000	0.0221	Do Not Test
Scenario 7 vs Scenario 2	980.500	7.219	Yes
Scenario 7 vs Scenario 5	707.500	5.209	Yes
Scenario 7 vs Scenario 6	436.500	3.214	Do Not Test
Scenario 7 vs Scenario 3	32.000	0.236	Do Not Test
Scenario 7 vs Scenario 4	31.500	0.232	Do Not Test
Scenario 7 vs Scenario 9	9.000	0.0663	Do Not Test
Scenario 7 vs Scenario 10	6.000	0.0442	Do Not Test
Scenario 7 vs Scenario 1	0.000	0.000	Do Not Test
Scenario 1 vs Scenario 2	980.500	7.219	Yes
Scenario 1 vs Scenario 5	707.500	5.209	Yes
Scenario 1 vs Scenario 6	436.500	3.214	Do Not Test
Scenario 1 vs Scenario 3	32.000	0.236	Do Not Test
Scenario 1 vs Scenario 4	31.500	0.232	Do Not Test
Scenario 1 vs Scenario 9	9.000	0.0663	Do Not Test
Scenario 1 vs Scenario 10	6.000	0.0442	Do Not Test
Scenario 10 vs Scenario 2	974.500	7.175	Yes
Scenario 10 vs Scenario 5	701.500	5.165	Yes
Scenario 10 vs Scenario 6	430.500	3.169	Do Not Test

Scenario 10 vs Scenario 3	26.000	0.191	Do Not Test
Scenario 10 vs Scenario 4	25.500	0.188	Do Not Test
Scenario 10 vs Scenario 9	3.000	0.0221	Do Not Test
Scenario 9 vs Scenario 2	971.500	7.152	Yes
Scenario 9 vs Scenario 5	698.500	5.143	Yes
Scenario 9 vs Scenario 6	427.500	3.147	Do Not Test
Scenario 9 vs Scenario 3	23.000	0.169	Do Not Test
Scenario 9 vs Scenario 4	22.500	0.166	Do Not Test
Scenario 4 vs Scenario 2	949.000	6.987	Yes
Scenario 4 vs Scenario 5	676.000	4.977	Yes
Scenario 4 vs Scenario 6	405.000	2.982	Do Not Test
Scenario 4 vs Scenario 3	0.500	0.00368	Do Not Test
Scenario 3 vs Scenario 2	948.500	6.983	Yes
Scenario 3 vs Scenario 5	675.500	4.973	Yes
Scenario 3 vs Scenario 6	404.500	2.978	Do Not Test
Scenario 6 vs Scenario 2	544.000	4.005	No
Scenario 6 vs Scenario 5	271.000	1.995	Do Not Test
Scenario 5 vs Scenario 2	273.000	2.010	Do Not Test

Note: The multiple comparisons on ranks do not include an adjustment for ties.

A result of "Do Not Test" occurs for a comparison when no significant difference is found between the two rank sums that enclose that comparison. For example, if you had four rank sums sorted in order, and found no significant difference between rank sums 4 vs. 2, then you would not test 4 vs. 3 and 3 vs. 2, but still test 4 vs. 1 and 3 vs. 1 (4 vs. 3 and 3 vs. 2 are enclosed by 4 vs. 2: 4 3 2 1). Note that not testing the enclosed rank sums is a procedural rule, and a result of Do Not Test should be treated as if there is no significant difference between the rank sums, even though one may appear to exist.

SO_2

Kruskal-Wallis One Way Analysis of Variance on Ranks Thursday, May 24, 2012, 10:15:16 PM

Data source: SO2 in GHG FINAL 2000-2012

Group	N	Missing	Median	25%	75%
Scenario 1	13	0	262.000	218.750	375.250
Scenario 2	13	0	786.000	657.000	1124.500
Scenario 3	13	0	786.000	657.000	1124.500
Scenario 4	13	0	786.000	634.750	1124.500
Scenario 5	13	0	521.000	438.250	750.000
Scenario 6	13	0	419.000	350.250	600.250
Scenario 7	13	0	537.000	442.000	750.000
Scenario 8	13	0	419.000	354.000	600.250
Scenario 9	13	0	524.000	427.000	750.000
Scenario 10	13	0	419.000	343.500	600.250

H = 71.950 with 9 degrees of freedom. (P = <0.001)

The differences in the median values among scenariosare greater than would be expected by chance; there is a statistically significant difference (P = <0.001)

To isolate the group or groups that differ from the others use a multiple comparison procedure.

All Pairwise Multiple Comparison Procedures (Tukey Test):

Comparison	Diff of Ranks	q	P<0.05
Scenario 3 vs Scenario 1	1145.000	8.430	Yes
Scenario 3 vs Scenario 10	754.000	5.551	Yes
Scenario 3 vs Scenario 6	743.500	5.474	Yes
Scenario 3 vs Scenario 8	741.500	5.459	Yes
Scenario 3 vs Scenario 5	481.500	3.545	No
Scenario 3 vs Scenario 9	473.000	3.482	Do Not Test
Scenario 3 vs Scenario 7	444.000	3.269	Do Not Test
Scenario 3 vs Scenario 4	21.500	0.158	Do Not Test
Scenario 3 vs Scenario 2	1.000	0.00736	Do Not Test
Scenario 2 vs Scenario 1	1144.000	8.422	Yes
Scenario 2 vs Scenario 10	753.000	5.544	Yes
Scenario 2 vs Scenario 6	742.500	5.466	Yes
Scenario 2 vs Scenario 8	740.500	5.452	Yes
Scenario 2 vs Scenario 5	480.500	3.538	Do Not Test
Scenario 2 vs Scenario 9	472.000	3.475	Do Not Test
Scenario 2 vs Scenario 7	443.000	3.261	Do Not Test
Scenario 2 vs Scenario 4	20.500	0.151	Do Not Test
Scenario 4 vs Scenario 1	1123.500	8.272	Yes
Scenario 4 vs Scenario 10	732.500	5.393	Yes
Scenario 4 vs Scenario 6	722.000	5.316	Yes
Scenario 4 vs Scenario 8	720.000	5.301	Yes
Scenario 4 vs Scenario 5	460.000	3.387	Do Not Test
Scenario 4 vs Scenario 9	451.500	3.324	Do Not Test
Scenario 4 vs Scenario 7	422.500	3.111	Do Not Test
Scenario 7 vs Scenario 1	701.000	5.161	Yes
Scenario 7 vs Scenario 10	310.000	2.282	No
Scenario 7 vs Scenario 6	299.500	2.205	Do Not Test

Scenario 7 vs Scenario 8	297.500	2.190	Do Not Test
Scenario 7 vs Scenario 5	37.500	0.276	Do Not Test
Scenario 7 vs Scenario 9	29.000	0.214	Do Not Test
Scenario 9 vs Scenario 1	672.000	4.947	Yes
Scenario 9 vs Scenario 10	281.000	2.069	Do Not Test
Scenario 9 vs Scenario 6	270.500	1.991	Do Not Test
Scenario 9 vs Scenario 8	268.500	1.977	Do Not Test
Scenario 9 vs Scenario 5	8.500	0.0626	Do Not Test
Scenario 5 vs Scenario 1	663.500	4.885	Yes
Scenario 5 vs Scenario 10	272.500	2.006	Do Not Test
Scenario 5 vs Scenario 6	262.000	1.929	Do Not Test
Scenario 5 vs Scenario 8	260.000	1.914	Do Not Test
Scenario 8 vs Scenario 1	403.500	2.971	No
Scenario 8 vs Scenario 10	12.500	0.0920	Do Not Test
Scenario 8 vs Scenario 6	2.000	0.0147	Do Not Test
Scenario 6 vs Scenario 1	401.500	2.956	Do Not Test
Scenario 6 vs Scenario 10	10.500	0.0773	Do Not Test
Scenario 10 vs Scenario 1	391.000	2.879	Do Not Test

Note: The multiple comparisons on ranks do not include an adjustment for ties.

A result of "Do Not Test" occurs for a comparison when no significant difference is found between the two rank sums that enclose that comparison. For example, if you had four rank sums sorted in order, and found no significant difference between rank sums 4 vs. 2, then you would not test 4 vs. 3 and 3 vs. 2, but still test 4 vs. 1 and 3 vs. 1 (4 vs. 3 and 3 vs. 2 are enclosed by 4 vs. 2: 4 3 2 1). Note that not testing the enclosed rank sums is a procedural rule, and a result of Do Not Test should be treated as if there is no significant difference between the rank sums, even though one may appear to exist.

YANBU

CO_2

Kruskal-Wallis One Way Analysis of Variance on Ranks

Data source: Data 1 in YANBU 2

Group	N	Missing	Median	25%	75%
100% NG	5	0	46.000	39.750	59.000
100% CO	5	0	60.000	52.000	77.000
100% DO	5	0	61.000	52.750	78.000
100% FO	5	0	64.000	54.500	81.000
50% NG VS 50% CO	5	0	53.000	45.750	68.000
70% NG VS 30% CO	5	0	51.000	44.000	64.000
50% NG VS 50% DO	5	0	54.000	46.500	68.000
70% NG VS 30% DO	5	0	51.000	44.000	65.000
50% NG VS 50% FO	5	0	55.000	47.500	70.000
70% NG VS 30% FO	5	0	52.000	44.000	66.000

H = 7.915 with 9 degrees of freedom. (P = 0.543)

The differences in the median values among scenariosare not great enough to exclude the possibility that the difference is due to random sampling variability; there is not a statistically significant difference (P = 0.543)

CH_4

Kruskal-Wallis One Way Analysis of Variance on Ranks

Data source: Data 2 in YANBU 2

Group	N	Missing	Median	25%	75%
100% NG	5	0	0.800	0.700	1.100
100% CO	5	0	2.500	2.125	3.200
100% DO	5	0	2.500	2.125	3.200
100% FO	5	0	2.500	2.125	3.200
50% NG VS 50% CO	5	0	1.700	1.400	2.100
70% NG VS 30% CO	5	0	1.300	1.150	1.700
50% NG VS 50% DO	5	0	1.700	1.275	2.000
70% NG VS 30% DO	5	0	1.300	1.150	1.700
50% NG VS 50% FO	5	0	1.700	1.400	2.100
70% NG VS 30% FO	5	0	1.300	1.150	1.700

H = 24.047 with 9 degrees of freedom. (P = 0.004)

The differences in the median values among scenariosare greater than would be expected by chance; there is a statistically significant difference (P = 0.004)

To isolate the group or groups that differ from the others use a multiple comparison procedure.

All Pairwise Multiple Comparison Procedures (Tukey Test):

Comparison	Diff of Ranks	q	P<0.05
100% CO vs 100% NG	156.000	4.786	Yes
100% CO vs 70% NG VS 30% FO	102.000	3.129	No
100% CO vs 70% NG VS 30% DO	102.000	3.129	Do Not Test
100% CO vs 70% NG VS 30% CO	102.000	3.129	Do Not Test
100% CO vs 50% NG VS 50% DO	76.000	2.332	Do Not Test
100% CO vs 50% NG VS 50% CO	63.500	1.948	Do Not Test
100% CO vs 50% NG VS 50% FO	63.500	1.948	Do Not Test
100% CO vs 100% FO	0.000	0.000	Do Not Test
100% CO vs 100% DO	0.000	0.000	Do Not Test
100% DO vs 100% NG	156.000	4.786	Yes
100% DO vs 70% NG VS 30% FO	102.000	3.129	Do Not Test
100% DO vs 70% NG VS 30% DO	102.000	3.129	Do Not Test
100% DO vs 70% NG VS 30% CO	102.000	3.129	Do Not Test
100% DO vs 50% NG VS 50% DO	76.000	2.332	Do Not Test
100% DO vs 50% NG VS 50% CO	63.500	1.948	Do Not Test
100% DO vs 50% NG VS 50% FO	63.500	1.948	Do Not Test
100% DO vs 100% FO	0.000	0.000	Do Not Test
100% FO vs 100% NG	156.000	4.786	Yes
100% FO vs 70% NG VS 30% FO	102.000	3.129	Do Not Test
100% FO vs 70% NG VS 30% DO	102.000	3.129	Do Not Test
100% FO vs 70% NG VS 30% CO	102.000	3.129	Do Not Test
100% FO vs 50% NG VS 50% DO	76.000	2.332	Do Not Test
100% FO vs 50% NG VS 50% CO	63.500	1.948	Do Not Test
100% FO vs 50% NG VS 50% FO	63.500	1.948	Do Not Test

50% NG VS 50% FO vs 100% NG	92.500	2.838	No
50% NG VS 50% vs 70% NG VS 30%	38.500	1.181	Do Not Test
50% NG VS 50% vs 70% NG VS 30%	38.500	1.181	Do Not Test
50% NG VS 50% vs 70% NG VS 30%	38.500	1.181	Do Not Test
50% NG VS 50% vs 50% NG VS 50%	12.500	0.383	Do Not Test
50% NG VS 50% vs 50% NG VS 50%	0.000	0.000	Do Not Test
50% NG VS 50% CO vs 100% NG	92.500	2.838	Do Not Test
50% NG VS 50% vs 70% NG VS 30%	38.500	1.181	Do Not Test
50% NG VS 50% vs 70% NG VS 30%	38.500	1.181	Do Not Test
50% NG VS 50% vs 70% NG VS 30%	38.500	1.181	Do Not Test
50% NG VS 50% vs 50% NG VS 50%	12.500	0.383	Do Not Test
50% NG VS 50% DO vs 100% NG	80.000	2.454	Do Not Test
50% NG VS 50% vs 70% NG VS 30%	26.000	0.798	Do Not Test
50% NG VS 50% vs 70% NG VS 30%	26.000	0.798	Do Not Test
50% NG VS 50% vs 70% NG VS 30%	26.000	0.798	Do Not Test
70% NG VS 30% CO vs 100% NG	54.000	1.657	Do Not Test
70% NG VS 30% vs 70% NG VS 30%	0.000	0.000	Do Not Test
70% NG VS 30% vs 70% NG VS 30%	0.000	0.000	Do Not Test
70% NG VS 30% DO vs 100% NG	54.000	1.657	Do Not Test
70% NG VS 30% vs 70% NG VS 30%	0.000	0.000	Do Not Test
70% NG VS 30% FO vs 100% NG	54.000	1.657	Do Not Test

N_2O

Kruskal-Wallis One Way Analysis of Variance on Ranks

Data source: Data 3 in YANBU 2

Group	N	Missing	Median	25%	75%
100% NG	5	0	0.1000	0.0750	0.1000
100% CO	5	0	0.500	0.450	0.600
100% DO	5	0	0.500	0.450	0.600
100% FO	5	0	0.500	0.450	0.600
50% NG VS 50% CO	5	0	0.300	0.250	0.400
70% NG VS 30% CO	5	0	0.200	0.175	0.300
50% NG VS 50% DO	5	0	0.300	0.250	0.400
70% NG VS 30% DO	5	0	0.200	0.175	0.300
50% NG VS 50% FO	5	0	0.300	0.250	0.400
70% NG VS 30% FO	5	0	0.200	0.175	0.300

H = 31.907 with 9 degrees of freedom. (P = <0.001)

The differences in the median values among scenariosare greater than would be expected by chance; there is a statistically significant difference (P = <0.001)

To isolate the group or groups that differ from the others use a multiple comparison procedure.

All Pairwise Multiple Comparison Procedures (Tukey Test):

Comparison	Diff of Ranks	q	P<0.05
100% CO vs 100% NG	176.000	5.399	Yes
100% CO vs 70% NG VS 30% FO	117.500	3.605	No
100% CO vs 70% NG VS 30% DO	117.500	3.605	Do Not Test
100% CO vs 70% NG VS 30% CO	117.500	3.605	Do Not Test
100% CO vs 50% NG VS 50% CO	75.500	2.316	Do Not Test
100% CO vs 50% NG VS 50% DO	75.500	2.316	Do Not Test
100% CO vs 50% NG VS 50% FO	75.500	2.316	Do Not Test
100% CO vs 100% FO	0.000	0.000	Do Not Test
100% CO vs 100% DO	0.000	0.000	Do Not Test
100% DO vs 100% NG	176.000	5.399	Yes
100% DO vs 70% NG VS 30% FO	117.500	3.605	Do Not Test
100% DO vs 70% NG VS 30% DO	117.500	3.605	Do Not Test
100% DO vs 70% NG VS 30% CO	117.500	3.605	Do Not Test
100% DO vs 50% NG VS 50% CO	75.500	2.316	Do Not Test
100% DO vs 50% NG VS 50% DO	75.500	2.316	Do Not Test
100% DO vs 50% NG VS 50% FO	75.500	2.316	Do Not Test
100% DO vs 100% FO	0.000	0.000	Do Not Test
100% FO vs 100% NG	176.000	5.399	Yes
100% FO vs 70% NG VS 30% FO	117.500	3.605	Do Not Test
100% FO vs 70% NG VS 30% DO	117.500	3.605	Do Not Test
100% FO vs 70% NG VS 30% CO	117.500	3.605	Do Not Test
100% FO vs 50% NG VS 50% CO	75.500	2.316	Do Not Test
100% FO vs 50% NG VS 50% DO	75.500	2.316	Do Not Test
100% FO vs 50% NG VS 50% FO	75.500	2.316	Do Not Test
50% NG VS 50% FO vs 100% NG	100.500	3.083	No
50% NG VS 50% vs 70% NG VS 30%	42.000	1.289	Do Not Test
50% NG VS 50% vs 70% NG VS 30%	42.000	1.289	Do Not Test
50% NG VS 50% vs 70% NG VS 30%	42.000	1.289	Do Not Test

50% NG VS 50% vs 50% NG VS 50%	0.000	0.000	Do Not Test
50% NG VS 50% vs 50% NG VS 50%	0.000	0.000	Do Not Test
50% NG VS 50% DO vs 100% NG	100.500	3.083	Do Not Test
50% NG VS 50% vs 70% NG VS 30%	42.000	1.289	Do Not Test
50% NG VS 50% vs 70% NG VS 30%	42.000	1.289	Do Not Test
50% NG VS 50% vs 70% NG VS 30%	42.000	1.289	Do Not Test
50% NG VS 50% vs 50% NG VS 50%	0.000	0.000	Do Not Test
50% NG VS 50% CO vs 100% NG	100.500	3.083	Do Not Test
50% NG VS 50% vs 70% NG VS 30%	42.000	1.289	Do Not Test
50% NG VS 50% vs 70% NG VS 30%	42.000	1.289	Do Not Test
50% NG VS 50% vs 70% NG VS 30%	42.000	1.289	Do Not Test
70% NG VS 30% CO vs 100% NG	58.500	1.795	Do Not Test
70% NG VS 30% vs 70% NG VS 30%	0.000	0.000	Do Not Test
70% NG VS 30% vs 70% NG VS 30%	0.000	0.000	Do Not Test
70% NG VS 30% DO vs 100% NG	58.500	1.795	Do Not Test
70% NG VS 30% vs 70% NG VS 30%	0.000	0.000	Do Not Test
70% NG VS 30% FO vs 100% NG	58.500	1.795	Do Not Test

Note: The multiple comparisons on ranks do not include an adjustment for ties.

A result of "Do Not Test" occurs for a comparison when no significant difference is found between the two rank sums that enclose that comparison. For example, if you had four rank sums sorted in order, and found no significant difference between rank sums 4 vs. 2, then you would not test 4 vs. 3 and 3 vs. 2, but still test 4 vs. 1 and 3 vs. 1 (4 vs. 3 and 3 vs. 2 are enclosed by 4 vs. 2: 4 3 2 1). Note that not testing the enclosed rank sums is a procedural rule, and a result of Do Not Test should be treated as if there is no significant difference between the rank sums, even though one may appear to exist.

NOx

Kruskal-Wallis One Way Analysis of Variance on Ranks

Data source: Data 4 in YANBU 2

Group	N	Missing	Median	25%	75%
100% NG	5	0	125.000	107.500	159.000
100% CO	5	0	166.000	143.500	212.000
100% DO	5	0	166.000	142.750	212.000
100% FO	5	0	166.000	143.500	212.000
50% NG VS 50% CO	5	0	145.000	125.000	185.000
70% NG VS 30% CO	5	0	137.000	118.000	175.000
50% NG VS 50% DO	5	0	145.000	125.000	185.000
70% NG VS 30% DO	5	0	137.000	118.000	175.000
50% NG VS 50% FO	5	0	145.000	125.000	185.000
70% NG VS 30% FO	5	0	137.000	118.000	175.000

H = 7.692 with 9 degrees of freedom. (P = 0.565)

The differences in the median values among scenariosare not great enough to exclude the possibility that the difference is due to random sampling variability; there is not a statistically significant difference (P = 0.565)

CO

Kruskal-Wallis One Way Analysis of Variance on Ranks

Data source: Data 5 in YANBU 2

Group	N	Missing	Median	25%	75%
100% NG	5	0	17.000	14.000	21.000
100% CO	5	0	12.000	10.500	16.000
100% DO	5	0	12.000	10.500	16.000
100% FO	5	0	12.000	10.500	16.000
50% NG VS 50% CO	5	0	15.000	12.250	19.000
70% NG VS 30% CO	5	0	15.000	13.250	20.000
50% NG VS 50% DO	5	0	15.000	12.250	19.000
70% NG VS 30% DO	5	0	15.000	13.250	20.000
50% NG VS 50% FO	5	0	15.000	12.250	19.000
70% NG VS 30% FO	5	0	15.000	13.250	20.000

H = 6.764 with 9 degrees of freedom. (P = 0.662)

The differences in the median values among scenariosare not great enough to exclude the possibility that the difference is due to random sampling variability; there is not a statistically significant difference (P = 0.662)

NMVOC

Kruskal-Wallis One Way Analysis of Variance on Ranks

Data source: Data 6 in YANBU 2

Group	**N**	**Missing**	**Median**	**25%**	**75%**
100% NG	5	0	4.000	3.500	5.000
100% CO	5	0	0.000	0.000	0.000
100% DO	5	0	4.000	3.500	5.000
100% FO	5	0	4.000	3.500	5.000
50% NG VS 50% CO	5	0	2.000	1.750	3.000
70% NG VS 30% CO	5	0	3.000	2.500	4.000
50% NG VS 50% DO	5	0	4.000	3.500	5.000
70% NG VS 30% DO	5	0	4.000	3.500	5.000
50% NG VS 50% FO	5	0	4.000	3.500	5.000
70% NG VS 30% FO	5	0	4.000	3.500	5.000

H = 22.742 with 9 degrees of freedom. (P = 0.007)

The differences in the median values among scenariosare greater than would be expected by chance; there is a statistically significant difference (P = 0.007)

To isolate the group or groups that differ from the others use a multiple comparison procedure.

All Pairwise Multiple Comparison Procedures (Tukey Test):

Comparison	**Diff of Ranks**	**q**	**P<0.05**
50% NG VS 50% FO vs 100% CO	141.000	4.326	No
50% NG VS 50% vs 50% NG VS 50%	88.500	2.715	Do Not Test
50% NG VS 50% vs 70% NG VS 30%	55.500	1.703	Do Not Test
50% NG VS 50% FO vs 100% DO	0.000	0.000	Do Not Test
50% NG VS 50% FO vs 100% FO	0.000	0.000	Do Not Test
50% NG VS 50% vs 70% NG VS 30%	0.000	0.000	Do Not Test
50% NG VS 50% FO vs 100% NG	0.000	0.000	Do Not Test
50% NG VS 50% vs 50% NG VS 50%	0.000	0.000	Do Not Test
50% NG VS 50% vs 70% NG VS 30%	0.000	0.000	Do Not Test
70% NG VS 30% DO vs 100% CO	141.000	4.326	Do Not Test
70% NG VS 30% vs 50% NG VS 50%	88.500	2.715	Do Not Test
70% NG VS 30% vs 70% NG VS 30%	55.500	1.703	Do Not Test
70% NG VS 30% DO vs 100% DO	0.000	0.000	Do Not Test
70% NG VS 30% DO vs 100% FO	0.000	0.000	Do Not Test
70% NG VS 30% vs 70% NG VS 30%	0.000	0.000	Do Not Test
70% NG VS 30% DO vs 100% NG	0.000	0.000	Do Not Test
70% NG VS 30% vs 50% NG VS 50%	0.000	0.000	Do Not Test
50% NG VS 50% DO vs 100% CO	141.000	4.326	Do Not Test
50% NG VS 50% vs 50% NG VS 50%	88.500	2.715	Do Not Test
50% NG VS 50% vs 70% NG VS 30%	55.500	1.703	Do Not Test
50% NG VS 50% DO vs 100% DO	0.000	0.000	Do Not Test
50% NG VS 50% DO vs 100% FO	0.000	0.000	Do Not Test
50% NG VS 50% vs 70% NG VS 30%	0.000	0.000	Do Not Test
50% NG VS 50% DO vs 100% NG	0.000	0.000	Do Not Test
100% NG vs 100% CO	141.000	4.326	Do Not Test
100% NG vs 50% NG VS 50% CO	88.500	2.715	Do Not Test

100% NG vs 70% NG VS 30% CO	55.500	1.703	Do Not Test
100% NG vs 100% DO	0.000	0.000	Do Not Test
100% NG vs 100% FO	0.000	0.000	Do Not Test
100% NG vs 70% NG VS 30% FO	0.000	0.000	Do Not Test
70% NG VS 30% FO vs 100% CO	141.000	4.326	Do Not Test
70% NG VS 30% vs 50% NG VS 50%	88.500	2.715	Do Not Test
70% NG VS 30% vs 70% NG VS 30%	55.500	1.703	Do Not Test
70% NG VS 30% FO vs 100% DO	0.000	0.000	Do Not Test
70% NG VS 30% FO vs 100% FO	0.000	0.000	Do Not Test
100% FO vs 100% CO	141.000	4.326	Do Not Test
100% FO vs 50% NG VS 50% CO	88.500	2.715	Do Not Test
100% FO vs 70% NG VS 30% CO	55.500	1.703	Do Not Test
100% FO vs 100% DO	0.000	0.000	Do Not Test
100% DO vs 100% CO	141.000	4.326	Do Not Test
100% DO vs 50% NG VS 50% CO	88.500	2.715	Do Not Test
100% DO vs 70% NG VS 30% CO	55.500	1.703	Do Not Test
70% NG VS 30% CO vs 100% CO	85.500	2.623	Do Not Test
70% NG VS 30% vs 50% NG VS 50%	33.000	1.012	Do Not Test
50% NG VS 50% CO vs 100% CO	52.500	1.611	Do Not Test

Note: The multiple comparisons on ranks do not include an adjustment for ties.

A result of "Do Not Test" occurs for a comparison when no significant difference is found between the two rank sums that enclose that comparison. For example, if you had four rank sums sorted in order, and found no significant difference between rank sums 4 vs. 2, then you would not test 4 vs. 3 and 3 vs. 2, but still test 4 vs. 1 and 3 vs. 1 (4 vs. 3 and 3 vs. 2 are enclosed by 4 vs. 2: 4 3 2 1). Note that not testing the enclosed rank sums is a procedural rule, and a result of Do Not Test should be treated as if there is no significant difference between the rank sums, even though one may appear to exist.

SO_2

ruskal-Wallis One Way Analysis of Variance on Ranks

Data source: Data 7 in YANBU 2

Group	N	Missing	Median	25%	75%
100% NG	5	0	0.000	0.000	0.000
100% CO	5	0	781.000	673.350	996.200
100% DO	5	0	383.000	330.600	489.000
100% FO	5	0	1446.600	1247.350	1845.200
50% NG VS 50% CO	5	0	390.500	336.675	498.100
70% NG VS 30% CO	5	0	234.000	202.000	298.800
50% NG VS 50% DO	5	0	191.700	165.300	244.500
70% NG VS 30% DO	5	0	115.000	99.200	146.700
50% NG VS 50% FO	5	0	723.300	623.625	922.600
70% NG VS 30% FO	5	0	434.000	374.175	553.500

H = 42.150 with 9 degrees of freedom. (P = <0.001)

The differences in the median values among scenariosare greater than would be expected by chance; there is a statistically significant difference (P = <0.001)

To isolate the group or groups that differ from the others use a multiple comparison procedure.

All Pairwise Multiple Comparison Procedures (Tukey Test):

Comparison	Diff of Ranks	q	P<0.05
100% FO vs 100% NG	219.000	6.719	Yes
100% FO vs 70% NG VS 30% DO	188.000	5.768	Yes
100% FO vs 50% NG VS 50% DO	159.000	4.878	Yes
100% FO vs 70% NG VS 30% CO	142.000	4.356	No
100% FO vs 100% DO	102.000	3.129	Do Not Test
100% FO vs 50% NG VS 50% CO	95.000	2.914	Do Not Test
100% FO vs 70% NG VS 30% FO	83.000	2.546	Do Not Test
100% FO vs 50% NG VS 50% FO	46.000	1.411	Do Not Test
100% FO vs 100% CO	31.000	0.951	Do Not Test
100% CO vs 100% NG	188.000	5.768	Yes
100% CO vs 70% NG VS 30% DO	157.000	4.817	Yes
100% CO vs 50% NG VS 50% DO	128.000	3.927	No
100% CO vs 70% NG VS 30% CO	111.000	3.405	Do Not Test
100% CO vs 100% DO	71.000	2.178	Do Not Test
100% CO vs 50% NG VS 50% CO	64.000	1.963	Do Not Test
100% CO vs 70% NG VS 30% FO	52.000	1.595	Do Not Test
100% CO vs 50% NG VS 50% FO	15.000	0.460	Do Not Test
50% NG VS 50% FO vs 100% NG	173.000	5.307	Yes
50% NG VS 50% vs 70% NG VS 30%	142.000	4.356	No
50% NG VS 50% vs 50% NG VS 50%	113.000	3.467	Do Not Test
50% NG VS 50% vs 70% NG VS 30%	96.000	2.945	Do Not Test
50% NG VS 50% FO vs 100% DO	56.000	1.718	Do Not Test
50% NG VS 50% vs 50% NG VS 50%	49.000	1.503	Do Not Test
50% NG VS 50% vs 70% NG VS 30%	37.000	1.135	Do Not Test
70% NG VS 30% FO vs 100% NG	136.000	4.172	No
70% NG VS 30% vs 70% NG VS 30%	105.000	3.221	Do Not Test
70% NG VS 30% vs 50% NG VS 50%	76.000	2.332	Do Not Test

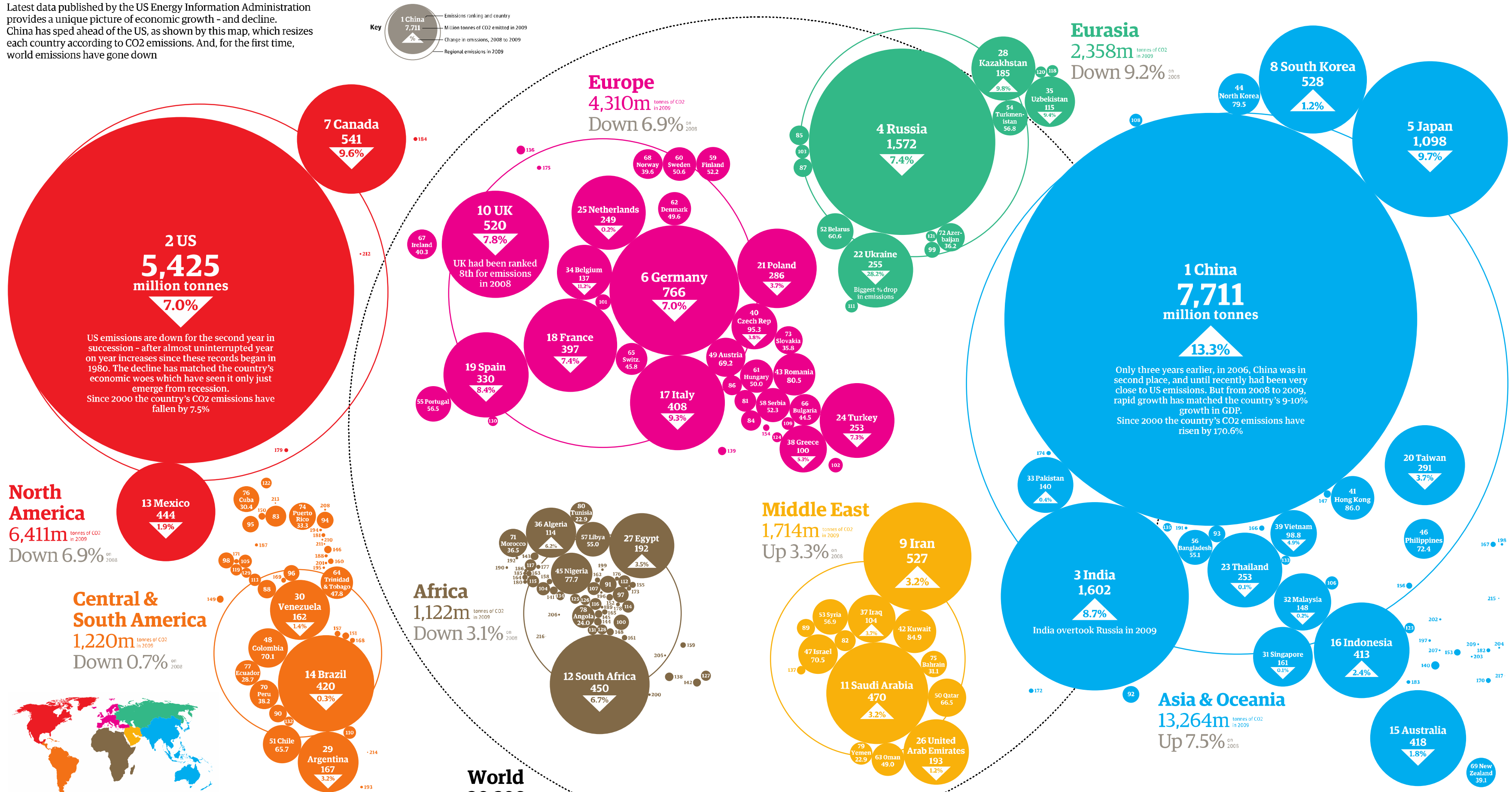
70% NG VS 30% vs 70% NG VS 30%	59.000	1.810	Do Not Test
70% NG VS 30% FO vs 100% DO	19.000	0.583	Do Not Test
70% NG VS 30% vs 50% NG VS 50%	12.000	0.368	Do Not Test
50% NG VS 50% CO vs 100% NG	124.000	3.804	Do Not Test
50% NG VS 50% vs 70% NG VS 30%	93.000	2.853	Do Not Test
50% NG VS 50% vs 50% NG VS 50%	64.000	1.963	Do Not Test
50% NG VS 50% vs 70% NG VS 30%	47.000	1.442	Do Not Test
50% NG VS 50% CO vs 100% DO	7.000	0.215	Do Not Test
100% DO vs 100% NG	117.000	3.589	Do Not Test
100% DO vs 70% NG VS 30% DO	86.000	2.638	Do Not Test
100% DO vs 50% NG VS 50% DO	57.000	1.749	Do Not Test
100% DO vs 70% NG VS 30% CO	40.000	1.227	Do Not Test
70% NG VS 30% CO vs 100% NG	77.000	2.362	Do Not Test
70% NG VS 30% vs 70% NG VS 30%	46.000	1.411	Do Not Test
70% NG VS 30% vs 50% NG VS 50%	17.000	0.522	Do Not Test
50% NG VS 50% DO vs 100% NG	60.000	1.841	Do Not Test
50% NG VS 50% vs 70% NG VS 30%	29.000	0.890	Do Not Test
70% NG VS 30% DO vs 100% NG	31.000	0.951	Do Not Test

Note: The multiple comparisons on ranks do not include an adjustment for ties.

A result of "Do Not Test" occurs for a comparison when no significant difference is found between the two rank sums that enclose that comparison. For example, if you had four rank sums sorted in order, and found no significant difference between rank sums 4 vs. 2, then you would not test 4 vs. 3 and 3 vs. 2, but still test 4 vs. 1 and 3 vs. 1 (4 vs. 3 and 3 vs. 2 are enclosed by 4 vs. 2: 4 3 2 1). Note that not testing the enclosed rank sums is a procedural rule, and a result of Do Not Test should be treated as if there is no significant difference between the rank sums, even though one may appear to exist.

An atlas of pollution: the world in carbon dioxide emissions

Latest data published by the US Energy Information Administration provides a unique picture of economic growth – and decline. China has sped ahead of the US, as shown by this map, which resizes each country according to CO2 emissions. And, for the first time, world emissions have gone down



Detailed data

Full list of each country's CO2 emissions and movement in the world emissions league table

Rank/change on 2008	Country	Million tonnes 2009	Percent change 08–09
= 1	China	7,711	13.3
= 2	US	5,425	-7.0
▲ 3	India	1,602	8.7
▼ 4	Russia	1,572	-7.4
= 5	Japan	1,098	-9.7
= 6	Germany	766	-7.0
= 7	Canada	541	-9.6
▲ 8	South Korea	528	1.2
▲ 9	Iran	527	3.2
▼ 10	UK	520	-7.8
▲ 11	Saudi Arabia	470	3.2
▼ 12	South Africa	450	-6.7
= 13	Mexico	444	-1.9
▲ 14	Brazil	420	-0.3
▲ 15	Australia	418	-1.8
▲ 16	Indonesia	413	2.4
▼ 17	Italy	408	-9.3
▼ 18	France	397	-7.4
= 19	Spain	330	-8.4
▲ 20	Taiwan	291	-3.7
▲ 21	Poland	286	-3.0
▼ 22	Ukraine	255	-28.2
▲ 23	Thailand	253	-0.1
▼ 24	Turkey	253	-7.3
= 25	Netherlands	249	-0.2
= 26	United Arab Emirates	193	-1.2
= 27	Egypt	192	3.5
▲ 28	Kazakhstan	185	9.8
▼ 29	Argentina	167	-3.2
= 30	Venezuela	162	-1.4
= 31	Singapore	161	-0.1
▲ 32	Malaysia	148	-0.2
▲ 33	Pakistan	140	0.4
▼ 34	Belgium	137	-11.2
▼ 35	Uzbekistan	115	-9.4
▼ 36	Algeria	114	6.2
▲ 37	Iraq	104	3.7
▼ 38	Greece	100	-5.3
▼ 39	Vietnam	98.8	-4.9
= 40	Czech Republic	95.3	-3.8
▲ 41	Hong Kong	86.0	10.3
= 42	Kuwait	84.9	6.3
▼ 43	Romania	80.5	-16.6
▲ 44	North Korea	79.5	14.3
▼ 45	Nigeria	77.7	-22.4
▼ 46	Philippines	72.4	-2.9
▲ 47	Israel	70.5	4.8
▲ 48	Colombia	70.1	7.9
▼ 49	Austria	69.2	-2.5
▲ 50	Qatar	66.5	4.8
▼ 51	Chile	65.7	-3.8
▼ 52	Belarus	60.6	-9.5
▲ 53	Syria	56.9	6.1
▼ 54	Turkmenistan	56.8	-1.2
▲ 55	Portugal	56.5	1.5
▲ 56	Bangladesh	55.1	9.4
▼ 57	Libya	55.0	-3.9
▲ 58	Serbia	52.3	-3.2
▼ 59	Finland	52.2	-4.9
▼ 60	Sweden	50.6	-7.7
▼ 61	Hungary	50.0	-10.7
▼ 62	Denmark	49.6	-8.6
▲ 63	Oman	49.0	9.9
= 64	Trinidad and Tobago	47.8	-4.1
▲ 65	Switzerland	45.8	1.0
▼ 66	Bulgaria	44.5	-11.9
▼ 67	Ireland	40.3	-11.2
= 68	Norway	39.6	-0.3
▲ 69	New Zealand	39.1	-1.1
▲ 70	Peru	38.2	4.0
▲ 71	Morocco	36.5	-2.2
▼ 72	Azerbaijan	36.2	-8.9
▼ 73	Slovakia	35.8	-4.5
= 74	Puerto Rico	33.3	-3.2
= 75	Bahrain	31.1	1.6
= 76	Cuba	30.4	4.7
= 77	Ecuador	28.7	1.7
= 78	Angola	24.0	1.8
▲ 79	Yemen	22.9	13.5
▲ 80	Tunisia	22.9	5.7
▼ 81	Croatia	21.5	-4.7
▲ 82	Jordan	20.0	2.4
▲ 83	Dominican Republic	19.9	2.1
▼ 84	Bosnia and Herzegovina	18.3	-15.9
▼ 85	Estonia	17.5	-11.8
▲ 86	Slovenia	17.4	0.5
▼ 87	Lithuania	15.8	-12.8
= 88	Panama	15.5	1.7
= 89	Lebanon	14.8	3.6
= 90	Bolivia	13.9	-2.7
▲ 91	Sudan	13.0	7.0
▲ 92	Sri Lanka	12.8	1.7
▼ 93	Burma	12.5	-9.5
▼ 94	US Virgin Islands	12.5	-3.5
▼ 95	Jamaica	12.1	-4.6
= 96	Netherlands Antilles	11.6	-4.1
▲ 97	Kenya	11.5	2.4
= 98	Guatemala	11.3	-1.4
▲ 99	Armenia	11.2	1.5
▲ 100	Zimbabwe	10.6	18.6
▼ 101	Luxembourg	10.6	-11.2
= 102	Cyprus	9.4	-3.5
▲ 103	Latvia	8.5	8.1
▲ 104	Ghana	8.1	9.6
= 105	Honduras	7.9	-2.4
▼ 106	Brunei	7.6	-27.1
▲ 107	Cameroon	7.5	-1.9
= 108	Mongolia	7.4	-3.8
▼ 109	Macedonia	7.3	-20.1
▼ 110	Uruguay	7.2	-10.2
= 111	Moldova	7.1	-4.1
▲ 112	Ethiopia	6.9	7.1
▼ 113	Costa Rica	6.8	-4.4
▲ 114	Tanzania	6.7	7.1
▼ 115	IvoryCoast	6.6	2.2
▲ 116	Congo	6.3	3.8
= 117	Senegal	6.2	1.8
▼ 118	Tajikistan	6.1	-10.4
= 119	El Salvador	5.9	0.0
= 120	Kyrgyzstan	5.7	-0.4
= 121	Georgia	5.3	-4.9
= 122	Bahamas	5.2	3.1
▲ 123	Papua New Guinea	4.8	6.7
▲ 124	Albania	4.6	3.8
▼ 125	Equatorial Guinea	4.6	-2.1
▼ 126	Gabon	4.6	-3.2
▼ 127	Mauritius	4.6	-1.0
▲ 128	Botswana	4.5	7.7
▼ 129	Nicaragua	4.5	-2.9
▼ 130	Gibraltar	4.4	-3.8
▲ 131	Namibia	4.1	3.7
▲ 132	Paraguay	4.0	3.7
▼ 133	Cambodia	3.9	-6.1
▲ 134	Benin	3.5	4.3
▲ 135	Nepal	3.4	3.8
▼ 136	Iceland	3.4	-7.4
▲ 137	Palestine	3.2	4.3
▲ 138	Madagascar	3.1	13.4
▼ 139	Malta	3.1	-2.5
▼ 140	New Caledonia	3.0	0.0
▲ 141	Togo	2.8	5.6
▼ 142	Reunion	2.8	0.0
▲ 143	Mauritania	2.7	5.3
▲ 144	Zambia	2.7	18.8
▼ 145	Congo, Dem Rep	2.7	-2.6
▼ 146	Martinique	2.6	6.3
▼ 147	Macau	2.4	1.3
▲ 148	Mozambique	2.3	4.6
▼ 149	Guadeloupe	2.2	-5.1
▲ 150	Haiti	2.1	2.9
▲ 151	Suriname	2.0	4.0
= 152	Uganda	1.9	-3.0
▼ 153	Fiji	1.9	-6.2
= 154	Montenegro	1.9	4.3
▲ 155	Djibouti	1.8	3.4
▼ 156	Guam	1.7	-3.5
= 157	Guyana	1.5	0.0
▲ 158	Burkina Faso	1.4	2.1
▲ 159	Seychelles	1.4	6.1
▼ 160	Barbados	1.4	-4.0
▲ 161	Swaziland	1.4	17.0
= 162	Niger	1.3	3.5
▼ 163	Guinea	1.3	-1.2
▲ 164	Sierra Leone	1.3	5.9
▼ 165	Malawi	1.3	4.6
= 166	Laos	1.2	1.1
▼ 167	Wake Island	1.2	-4.3
= 168	French Guiana	1.1	6.1
= 169	Aruba	1.1	4.2
▲ 170	French Polynesia	1.1	7.7
▼ 171	Belize	0.94	-5.4
= 172	Maldives	0.92	3.4
= 173	Somalia	0.90	3.4
= 174	Afghanistan	0.83	-2.9
= 175	Faroe Islands	0.80	6.4
▲ 176	Eritrea	0.77	6.4
▲ 177	Mali	0.74	6.4
▼ 178	Rwanda	0.74	0.0
= 179	Bermuda	0.71	4.2
= 180	Liberia	0.69	2.2
= 181	Antigua and Barbuda	0.69	4.4
= 182	American Samoa	0.67	2.2
▲ 183	East Timor	0.63	8.7
▼ 184	Greenland	0.61	-4.8
▲ 185	Guinea-Bissau	0.46	0.0
▲ 186	Gambia	0.44	15.4
▼ 187	Cayman Islands	0.43	-11.8
▼ 188	Saint Lucia	0.41	0.0
▲ 189	Burundi	0.37	4.0
▲ 190	Cape Verde	0.34	4.5
▼ 191	Bhutan	0.33	-11.1
▲ 192	Western Sahara	0.32	0.0
▲ 193	Antarctica	0.31	17.6
▲ 194	Saint Kitts and Nevis	0.30	11.1
= 195	Grenada	0.30	4.8
▼ 196	Central African Republic	0.29	-13.0
▲ 197	Solomon Islands	0.29	25.0
▼ 198	US Pacific Islands	0.29	0.0
▼ 199	Chad	0.29	11.1
▼ 200	Lesotho	0.27	5.9
= 201	Saint Vincent/Grenadines	0.27	17.6
▲ 202	Nauru	0.20	9.1
▼ 203	Tonga	0.15	-23.1
▲ 204	Cook Islands	0.15	66.7
▲ 205	Comoros	0.15	25.0
▼ 206	Sao Tome and Principe	0.15	11.1
▲ 207	Vanuatu	0.15	25.0
▲ 208	British Virgin Islands	0.15	25.0
▼ 209	Samoa	0.15	-16.7
= 210	Montserrat	0.15	58.7
▼ 211	Dominica	0.14	11.1
▼ 212	Saint Pierre and Miquelon	0.11	16.7
= 213	Turks and Caicos Islands	0.08	0.0
= 214	Falkland Islands	0.05	0.0
= 215	Kiribati	0.04	0.0
= 216	Saint Helena	0.01	11.2
= 217	Niue	0.01	2.9

Table shows total carbon dioxide emissions from the consumption of energy

GRAPHIC: MARK McCORMICK, PAUL SCRUTON. SOURCE: EIA

GHG Emissions by Sector in 2005

CO2, CH4, N2O, PFCs, HFCs, SF6
(excludes land use change)

Saudi Arabia

Sector	MtCO2e	%
Energy	326.2	86.6
Electricity & Heat	171.9	45.7
Manufacturing & Construction	72.0	19.1
Transportation	74.2	19.7
Other Fuel Combustion	4.9	1.3
Fugitive Emissions [1]	3.1	0.8
Industrial Processes	15.5	4.1
Agriculture	11.9	3.2
Waste	22.9	6.1
Total	**376.5**	

Middle East & N. Africa

Sector	MtCO2e	%
Energy	2,056.4	83.8
Electricity & Heat	772.0	31.4
Manufacturing & Construction	367.9	15.0
Transportation	388.2	15.8
Other Fuel Combustion	276.8	11.3
Fugitive Emissions [1]	251.5	10.2
Industrial Processes	117.8	4.8
Agriculture	181.7	7.4
Waste	99.2	4.0
Total	**2,455.2**	

CURRICULUM VITAE

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EDUCATIONAL QUALIFICATION:

2007 - 2012:	M.Sc. Environmental Sciences, King Fahd University of Petroleum and Minerals (KFUPM).
1992 - 1998:	B.Sc. Applied Chemical Engineering King Fahd University of Petroleum and Minerals (KFUPM).

WORK EXPERIENCE

2005 – Till date.	Hazardous Waste Supervisor; Environmental Control Department. Royal Commission for Jubail and Yanbu
2003 - 2005.	Sales Engineer; Sigma Paint. Saudi Arabia.
2000 - 2003.	Sales Engineer; Helmet Paint. Saudi Arabia.

LANGUAGES:

Arabic and English.